SIMULATION STUDY OF LIGHT WEIGHT CRASHWORTHINESS OF CAR BUMPER IN FRONTAL CRASH

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Abstract: *Protecting a car in a low-speed collision is an essential for passenger safety. A box-shaped bumper beams were common and served as shock absorbers in a potential crash. In this simulation study, their comparative deformation and failure analysis of hollow and solid bumper beam is investigated. In this study, Aluminium 6061 T4 is used for the analysis. The crash phenomenon is simulated in which the vehicle hits a deformable concrete wall at a specified speed. Modeling of solid and hollow car bumper is approximated from Honda Civic car's width and design. The bumper beam, actuating tubes and the retention plates supporting the beam and the concrete wall are modeled as deformable bodies. The crash event is simulated using the elastic–plastic finite element model through Von Mises yield criteria and isotropic hardening rule. The deformation behaviour and ductile failure of the solid and hollow bumper is predicted in the form of plastic strain localization in this study and compared.*

Keywords: Car bumper beam, deformation analysis, Finite element analysis, crash phenomenon.

I. INTRODUCTION

An automobile's bumpers are meant to reduce injury to vehicle occupants in collisions, but are increasingly designed to reduce injury to pedestrians struck by cars. What were then, simple metal beams attached to the front of a car has evolved into complex, engineered components that are integral to the protection of the vehicle in collisions. Automobile bumper comprises of the bumper system (Baldwin, 2013).The bumper system is comprised of bumper beam, actuating tubes and retention plates. In testing of bumpers, four parameters are important. Firstly, the material, how the material type can affect the impact specification and how different materials can be used as replacement to lower the part weights. Here the effect of modulus of elasticity and yield strength are considered for the impact behaviour of bumper beam. Secondly, how the thickness of the bumper beam can affect the impact specification. Thirdly, how even small changes and modification to the shape can result in easier manufacturing processes without lowering the impact strength for lessening the material volume. Finally how the impact condition can affect the impact behaviour. A good design of bumper provides safety for passengers and has low weight according to Researcher Marzbanrad et al., 2009 . Besides safety reasons, emission regulation and fuel efficiency also encourages the manufacturer to reduce the weight as said by Hosseinzadeh et al., 2005 . Researcher Thacker et al., 1998 conducted crash-testing simulation study of a 1997 Honda Accord. The vehicle was stripped down to its basic parts, and each component was analyzed considering different material properties. A similar study was carried out by Abdel-Nasser, 2013 where he conducted crash simulation on different types of lightning columns and predicted the variation of the columns thickness with the energy absorption capacity thus modeled lightning columns instead of car bumper. Researcher Tanlak et al., 2015 developed a correction factor in order to account for the energy absorbed by the deformable barrier. The principal factors that affect the energy absorption capability material, structural geometry and loading mode, the energy dissipating mechanisms of metallic and composite structures are considerably different. The structures made from composite materials are normally brittle and dissipate energy through different combined fracture mechanisms such as delamination, fiber breakage, and matrix cracking, whereas the ductility nature of metallic structures allows them to dissipate energy through progressive plastic deformation (Mamalis et al.,1997).Various research works were done, and many experiments were conducted for determination of material in frontal car crash test and various designs of bumper and their behavior have been studied (Ashtikar et al.,2016). This work focuses on application of aluminium alloy as a material for the bumper beam and energy absorption and deformation characteristics of the bumper beams is studied.

1. DESIGN OF CAR BUMPER BEAM USING CREO 3.0 PARAMETRIC SOFTWARE

Modeling of solid and hollow car bumper as shown in *Figure 1* is done with help of Creo CAD software. The design and dimension of the car bumper is approximated from Honda Civic car's width and design (Malaysia H. Honda Civic Sedan Specifications), Dimensions of car bumper beam is taken as follows: Length of bumper beam: 1800 mm, Width of bumper beam: 100 mm, Angle of bumper beam: 34.37°, Thickness of bumper beam: 50 mm, Width and length of retention plate of bumper beam: 120 mm, Thickness of retention Plate: 20 mm. Modeling of hollow car bumper as shown in *Figure 2* is done with help of Creo CAD software. The design and dimension of the car bumper is approximated from Honda Civic car's width and design (Malaysia H. Honda Civic Sedan Specifications), Dimensions of car bumper beam is taken as follows: Length of bumper beam: 1800 mm, Width of bumper beam: 100 mm, Angle of bumper beam: 34.37°, Thickness of bumper beam: 50 mm, Shell thickness: 10 mm, Width and length of retention plate of bumper beam: 120 mm, Thickness of retention Plate: 20 mm.

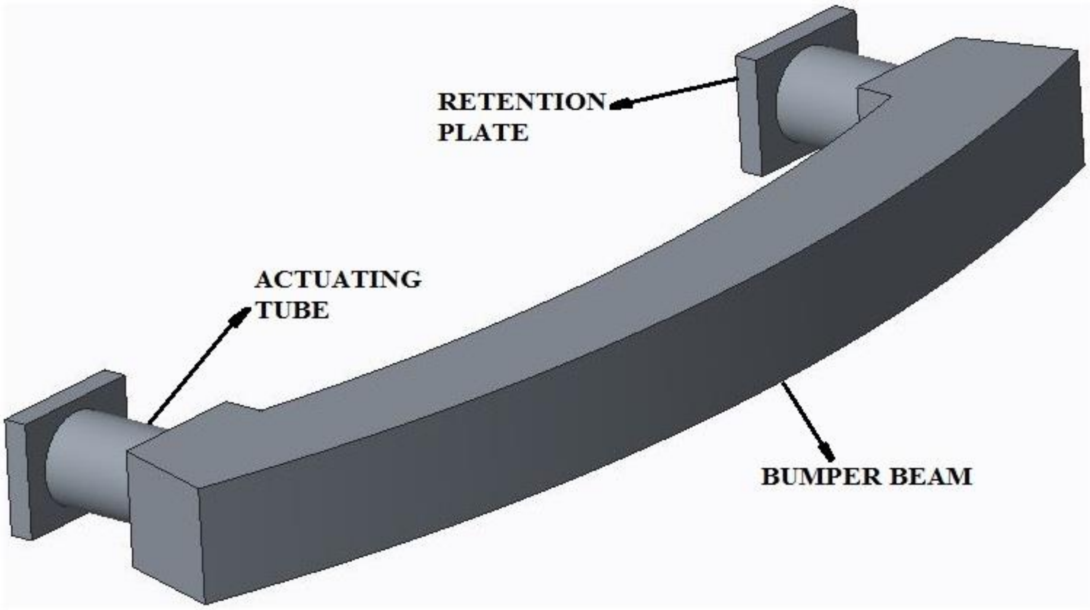


Figure 1: Designed of solid bumper beam

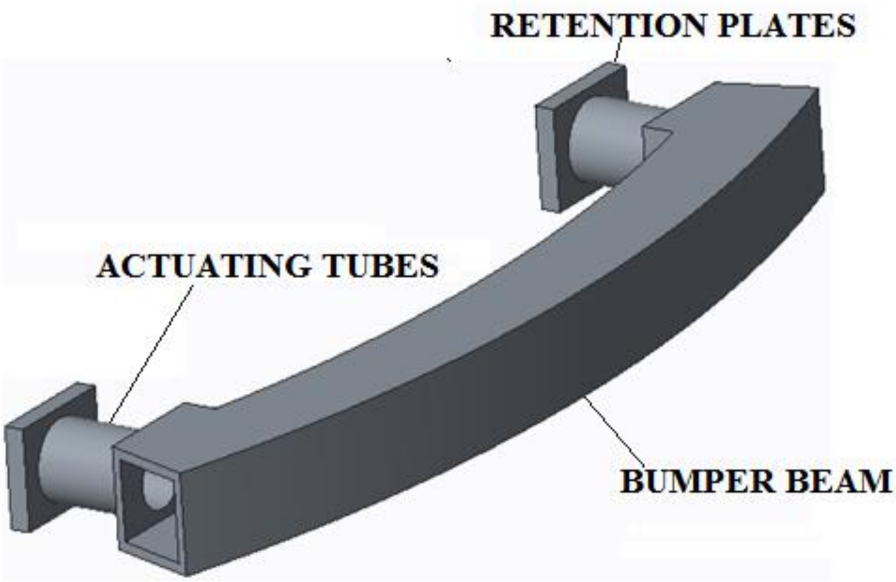


Figure 2: Designed of hollow bumper beam

2. RESULTS AND DISCUSSION

2.1 Finite element simulation

Commercially available software Abaqus FEA was used to perform this simulation. Following assumptions were made to carry out the simulation for hollow and solid bumper beam: i) The beam is modeled as deformable body and is provided with a specific velocity, and its degree of freedom is one, i.e. only translation freedom in one direction was allowed. ii) The concrete wall that is considered as deformable structure is fixed and stationary. In this dynamic analysis the beam is movable, while the analytical wall is constrained from all sides. The bumper beam was considered homogenous and isotropic and overall strength and ductility properties of Aluminium 6061 T4 was consider for the simulation and the plastic properties of Aluminium 6061 T4 was calculated from Hollomon Equation (Zhang et al., 2004) and plotted and shown in *Figure 3* and the properties for concrete were obtained from (Bogataj et al., 2013).

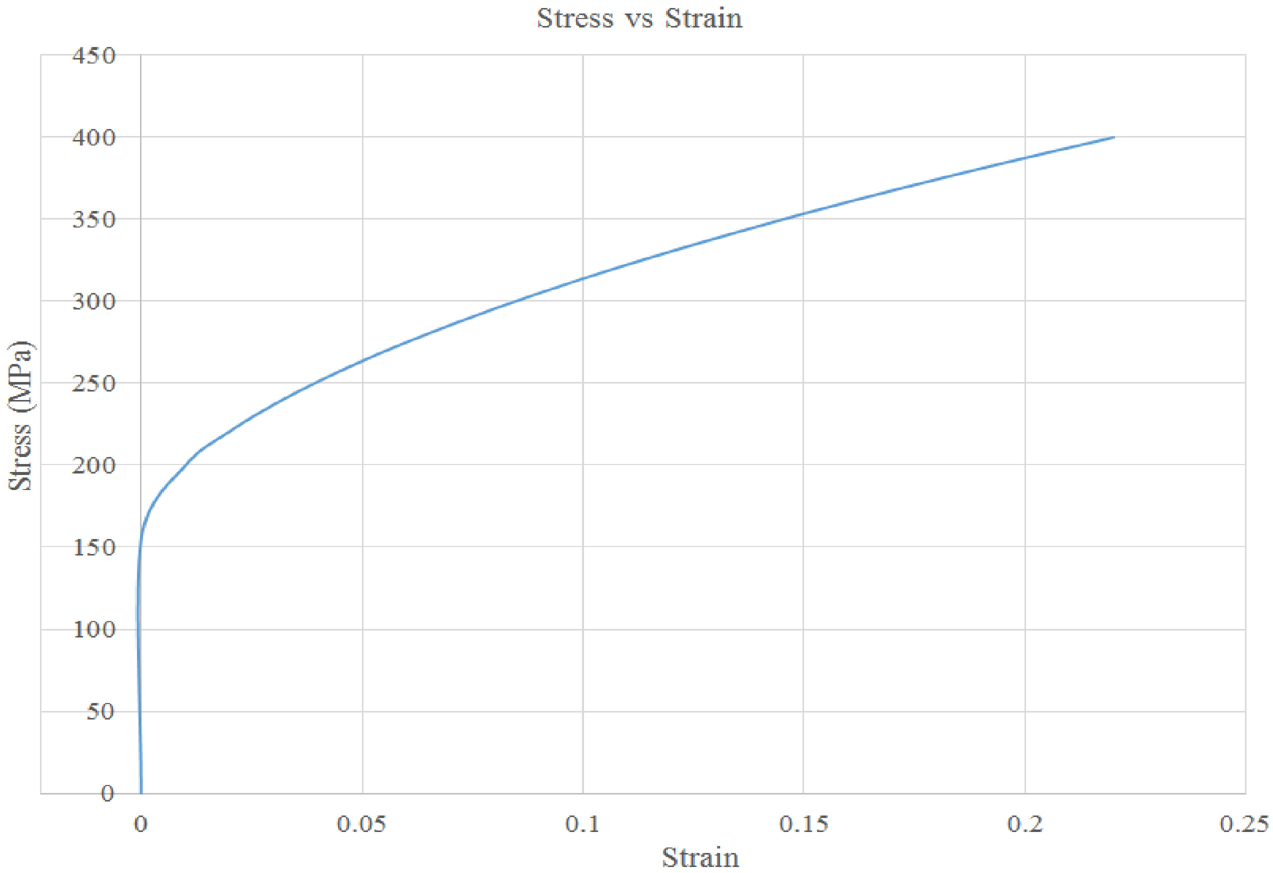


Figure 3: stress-strain data from Hollomon equation

As shown in *Figure 4* the hollow bumper beam is meshed with C3D4 linear tetrahedral elements with total number of elements 1834 and total number of nodes 2648and wall is considered as deformable. As shown in *Figure 5* the solid bumper beam was meshed with C3D4 linear tetrahedral elements with total number of elements 6674 and total number of nodes 1662 and wall is considered as deformable.

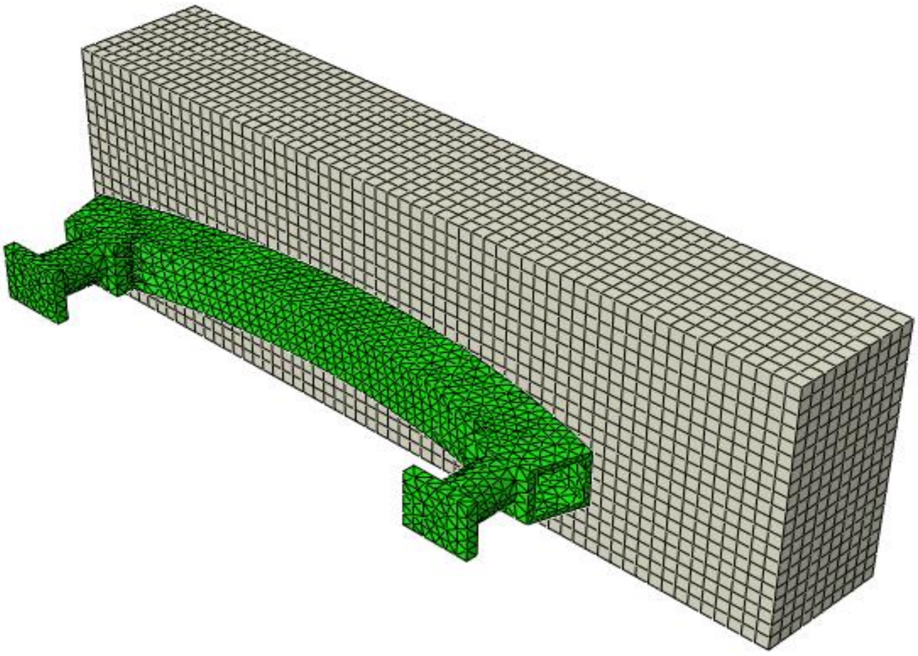


Figure 4: Hollow bumper beam meshed with C3D4 tetrahedral element

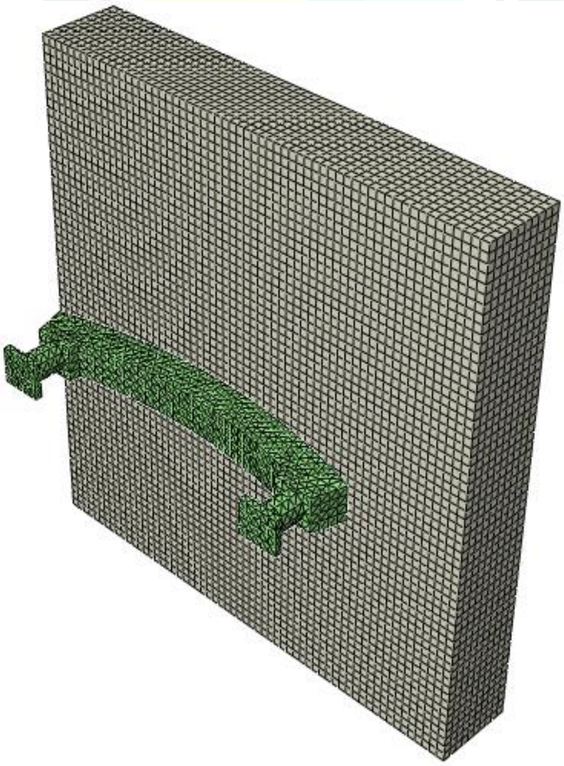


Figure 5: solid bumper beam meshed with C3D4 tetrahedral element

The inputs that were taken for impact simulation were: density of aluminium =2.7 × 10^{-6} kg/mm^3, plastic stress and plastic strain data obtained from Hollomon's equation, Modulus of elasticity = 70000 MPa, Poisson ratio = 0.33, Impact velocity = 17,777.7778 mm/s, Surface friction coefficient = 0.4. *Figure 6* and *Figure 7* shows the Von Misses Stresses occurring in the hollow and solid bumper beam respectively. It is observed that the initial contact between the beam and the wall involves a curved front face with sharp edges at the boundary thus resulting in stress concentration at the edges (Dundurs and Lee,1972) and the failure starts from the contact point and proceeds towards the back face of the beam for both cases, It is also observed that the rate at which the inner molecules are stressed is more for solid bumper beam than for hollow bumper beam, thus the resistance to deformation shown by the solid bumper beam is comparatively faster than hollow bumper beam.

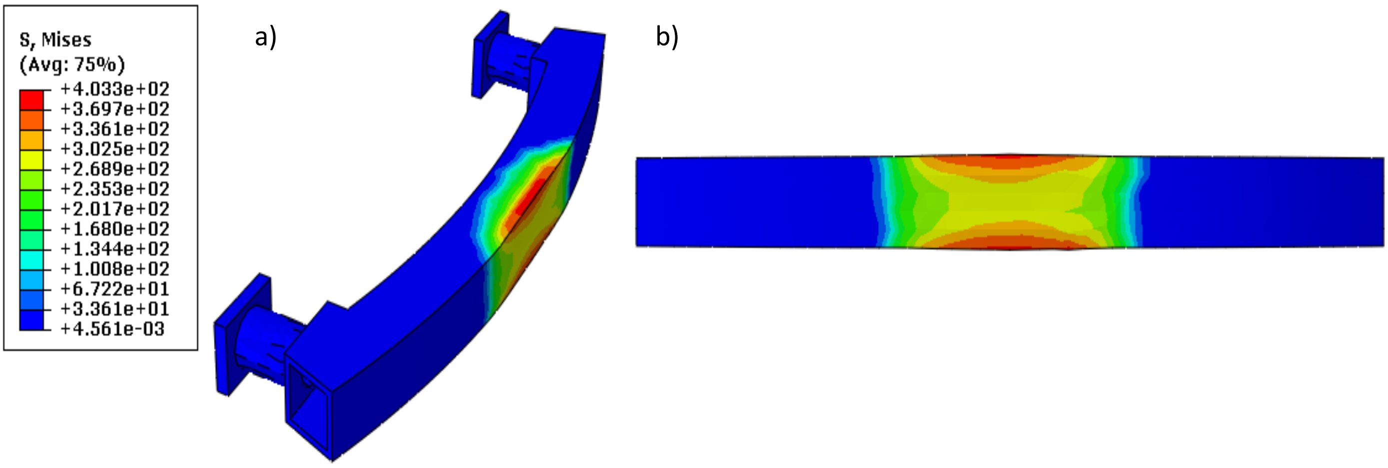


Figure 6: Von Misses Stress distribution of hollow bumper beam at 5 ms, a) Isometric view b) Front view

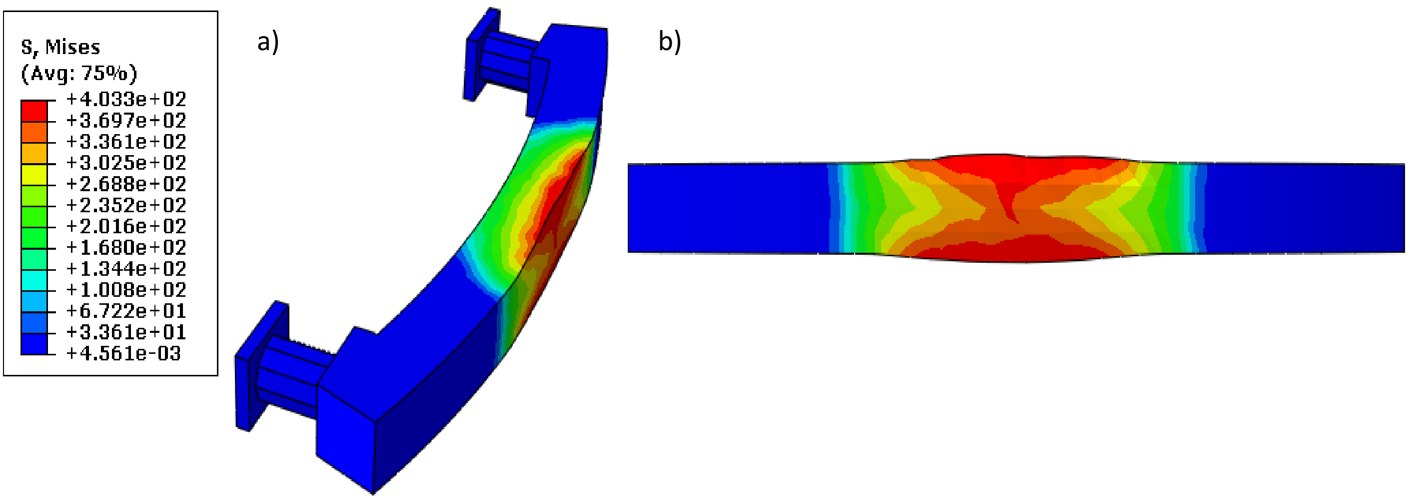


Figure 7: Von Misses Stress distribution of solid bumper beam at 5 ms, a) Isometric view b) Front view

In *Figure 8* and *Figure 9*, it is observed for the hollow bumper beam, the center area does not take part in the impact resistance for longer period of time, as the stress generation at this area gets reduced. This is due to the reason, the hollow beam starts to get crushed and simultaneously the centre area is pushed inwards, and this area in turn loses contact with the wall. While for the solid bumper beam, this is not observed as it is not hollow and thus the area although deformed continues to stick with the wall, and acts as a cushion for inner molecules.

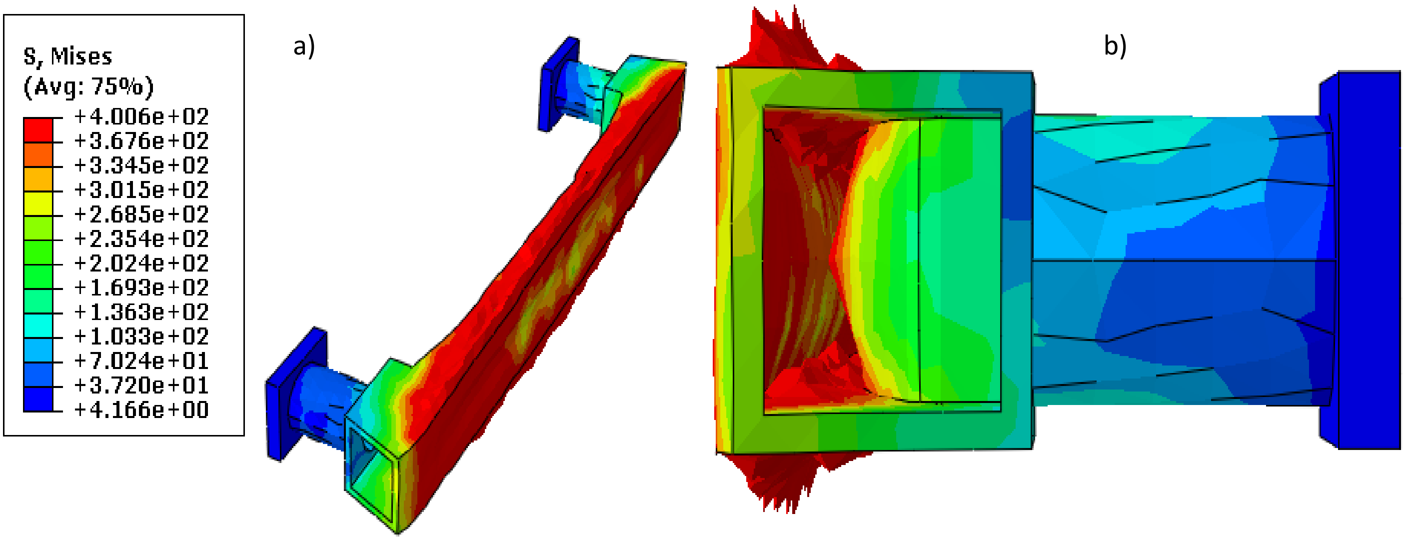


Figure 8: Von misses stress distribution of hollow bumper beam at 10ms, a) Isometric view b) side view

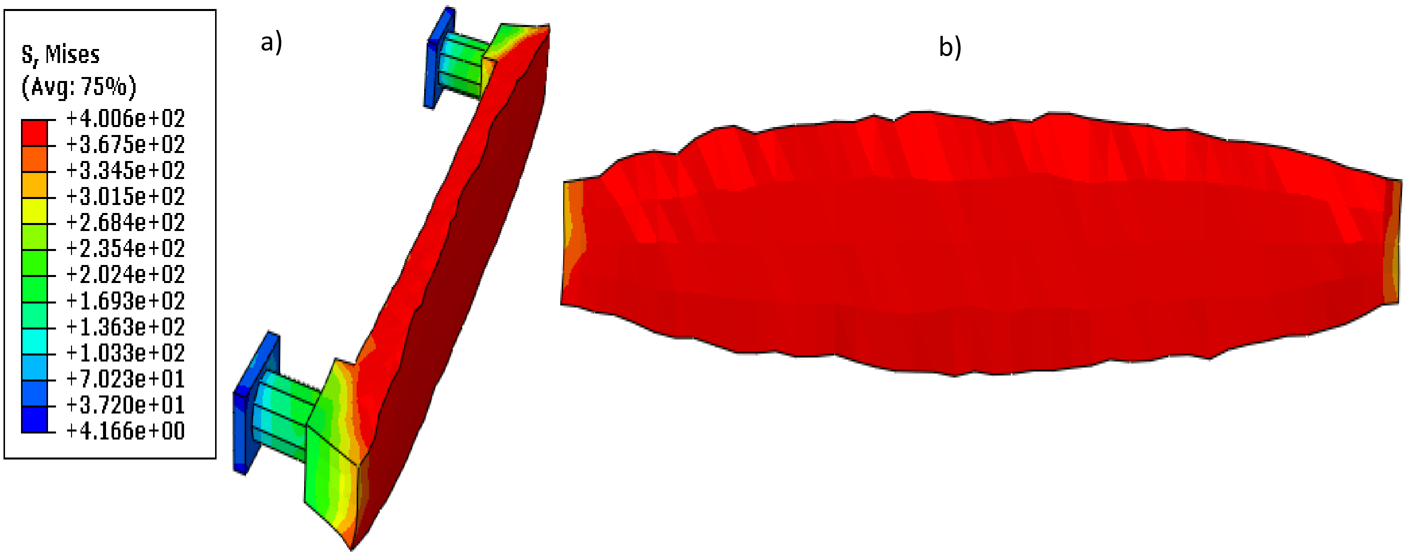


Figure 9: Von misses stress distribution of solidbumper beam at 10ms, a) Isometric view b) front view

This observations can be verified by observing the plastic equivalent strain for both hollow and solid bumper beam for the same time period, it is observed that for hollow beam outer edges are strained as the central area is pushed inwards but for the solid beam the maximum strain occurs around the central area and the whole body deforms, This can be verified from the *Figure 10* and *Figure 11*.

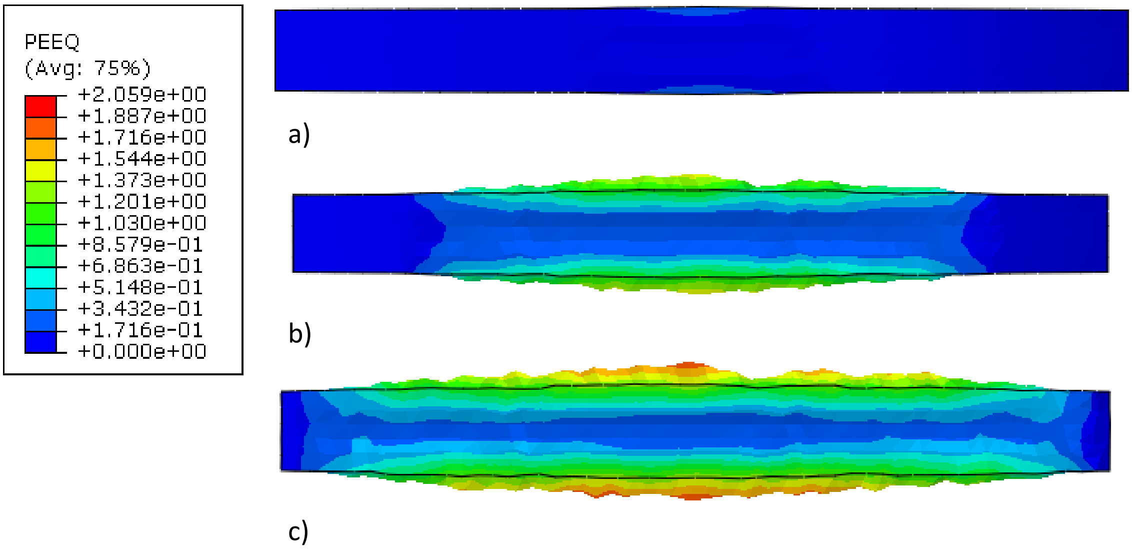


Figure 10: Plastic equivalent strain distribution of hollow beam with respect to time, a) 5ms b) 8ms c) 10 ms

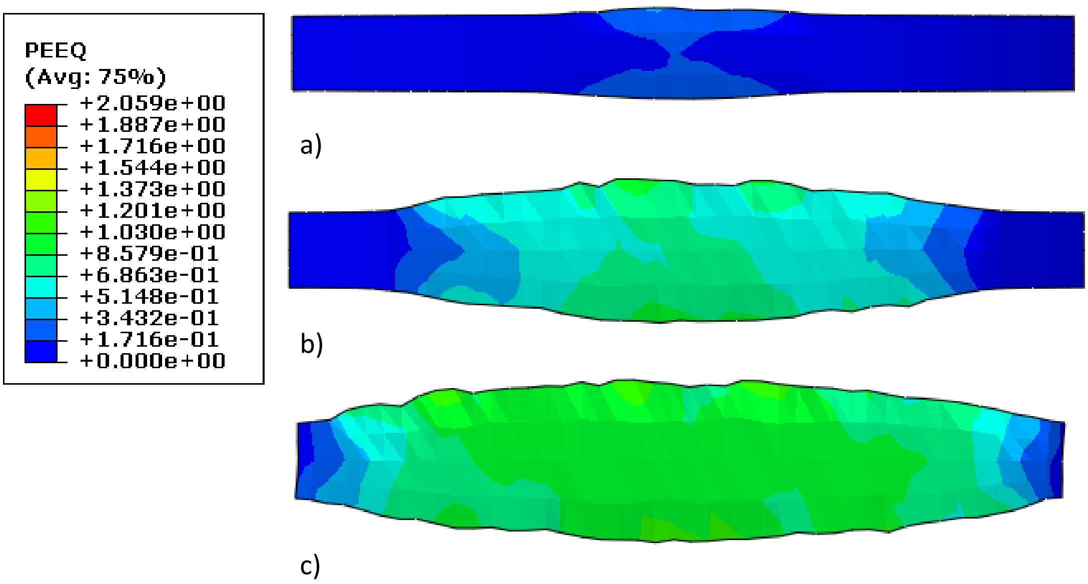


Figure 11: Plastic equivalent strain distribution of solid beam with respect to time, a) 5ms b) 8ms c) 10 ms

In *Figure 12* shows that the actuating tubes gets crushed but is less deformed for hollow bumper beam. It is also observed that the strain occurred for hollow bumper beam is significantly more with respect to solid bumper beam and the deformation for hollow bumper beam is uneven

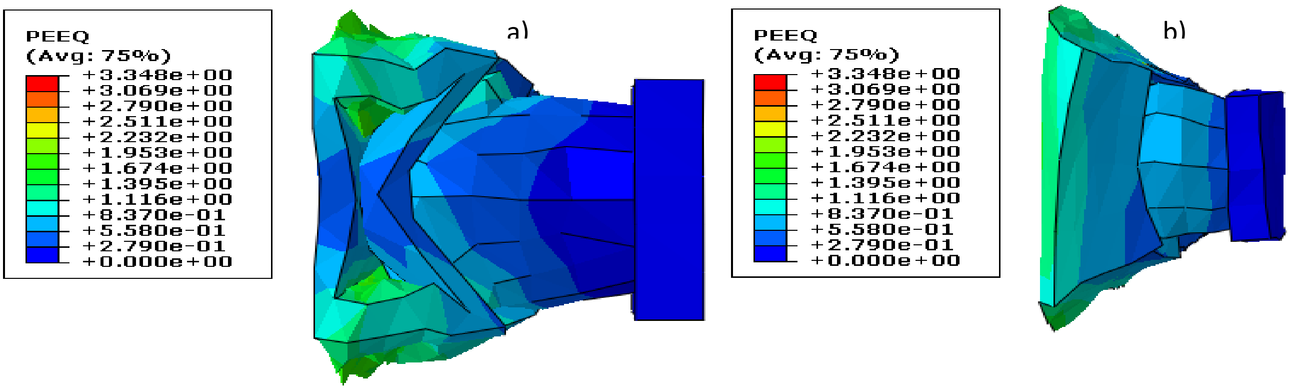
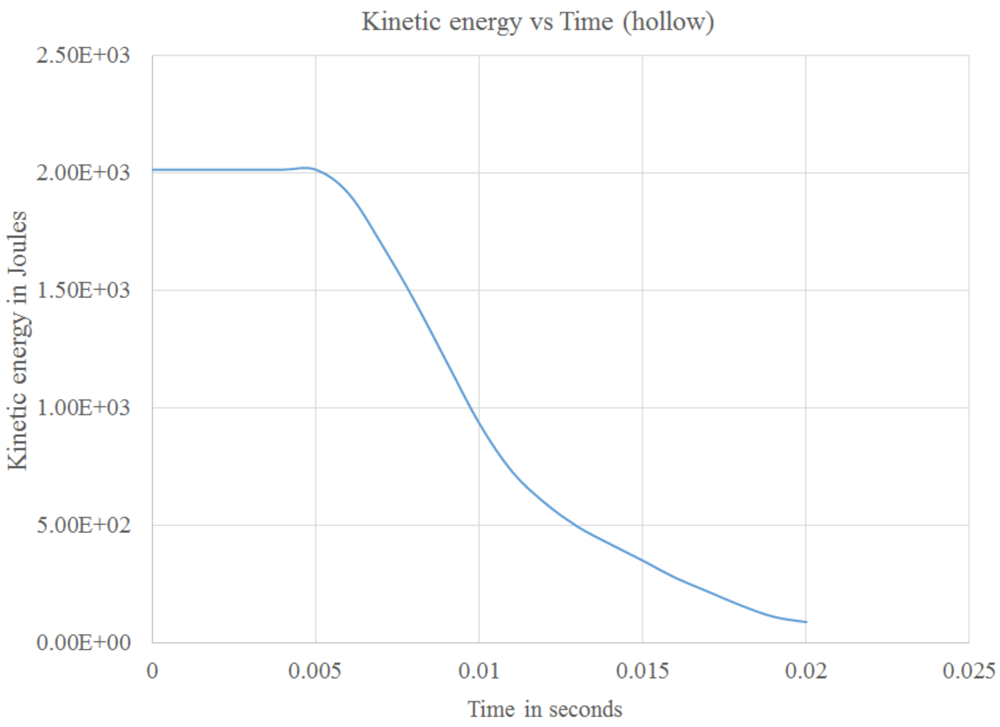
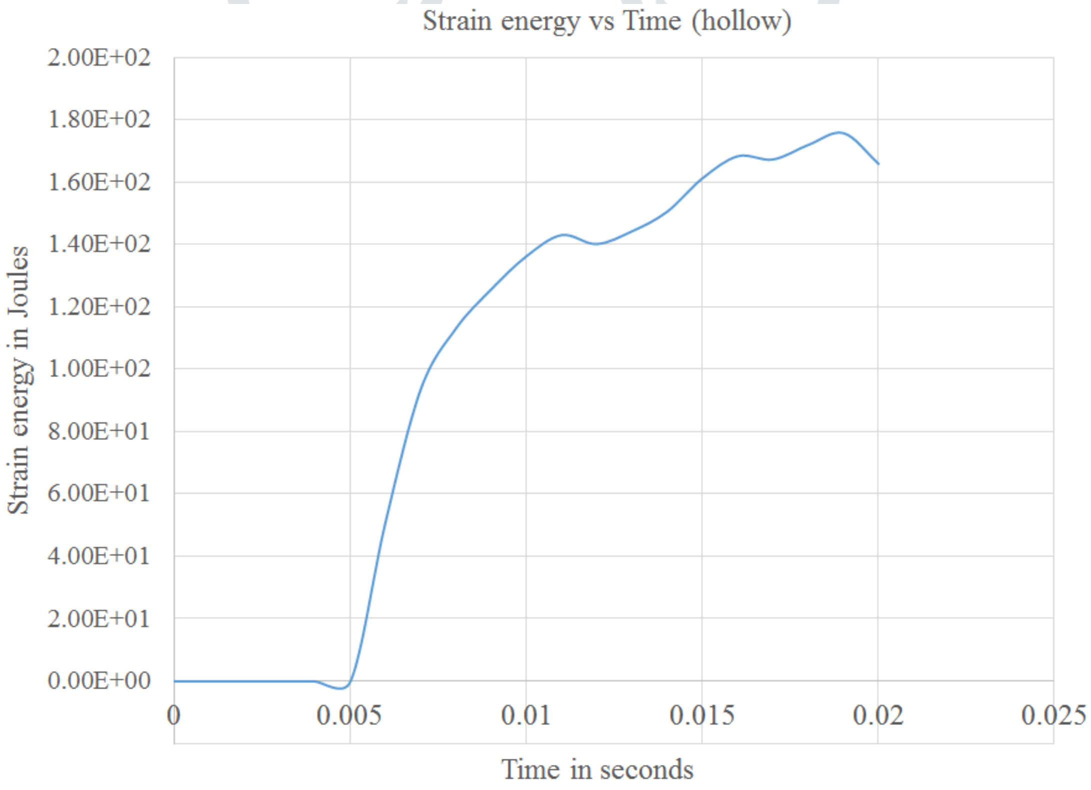


Figure 12: Plastic equivalent strain distribution for a) hollow bumper beamb) solid bumper beam, at 17ms.

The energy graphs of hollow and solid bumper beams as shown in *Figure 13* and *Figure 14* respectively show that the kinetic energy is steadily dissipated while the strain energy fluctuates for both the cases. At the time of contact due to impact collision, localized molecular slip takes place which results in the dip of the strain energy curve for both the hollow and solid bumpers. The initial increase in strain energy shows that the material initially in contact during this time period has no molecular slip or any other form of energy dissipation, thus the material in contact starts absorbing the kinetic energy in both the hollow and solid bumper. After an increase in strain energy for both the bumpers, for the same time period the solid bumper reaches a very high value of strain energy (greater than 80 x 10^7 J) and thus molecular slip occurs which results in the dip of the energy curve after it has reached a peak value and at the same time period the hollow bumper reaches a very low value of strain energy (less than 14 x 10^7 J) after which it is observed that it keeps on rising and afterwards fluctuates due to small amount of localized molecular slip (compared to solid bumper), otherwise keeping an overall increasing trend. The increases in strain energy after the sudden drop in both the cases because of the unstrained molecules are taking part in absorption of the rest of the energy. During the whole period the kinetic energy is steadily dissipated for both the hollow and solid bumpers.

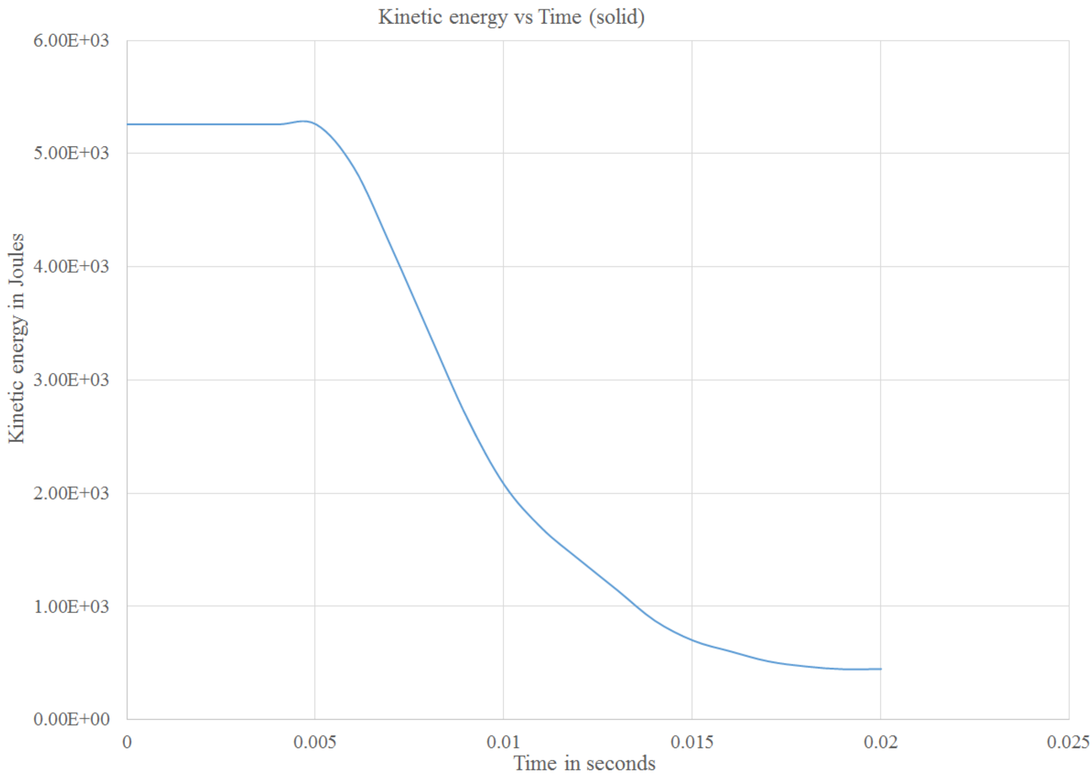


(a)

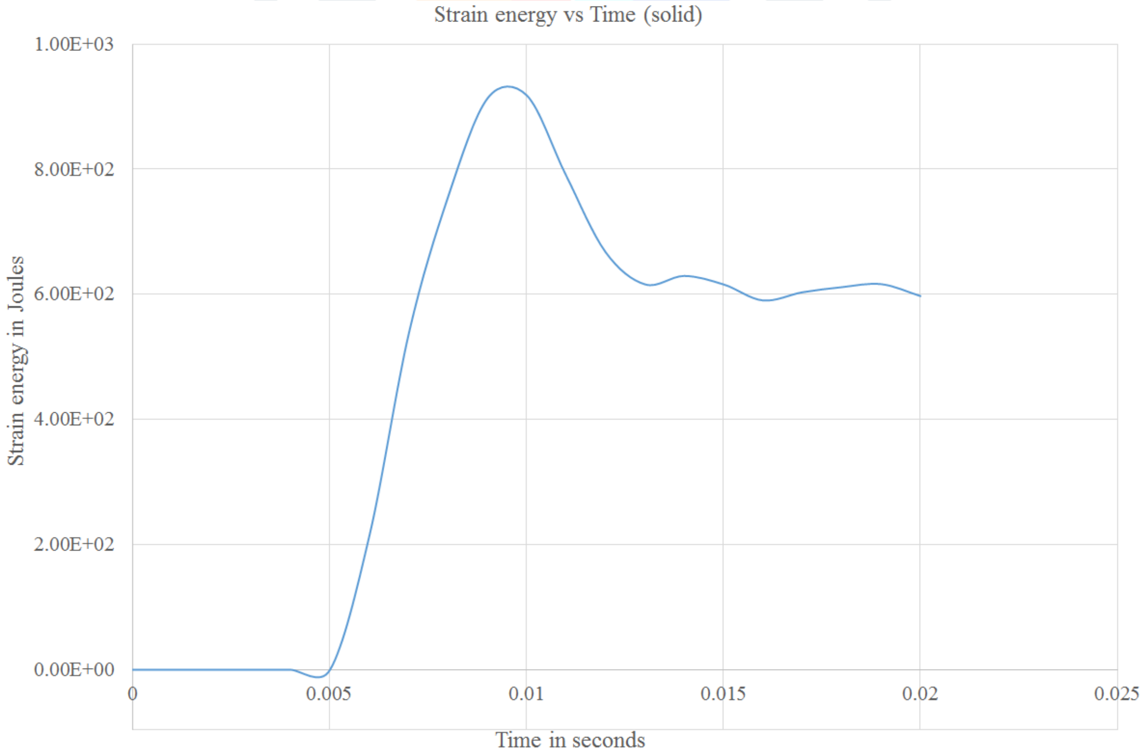


(b)

Figure 13: Energy graph of hollow bumper beam a) Kinetic energy dissipated, b) strain energy absorbed



(a)



(b)

Figure 14: Energy graph ofsolid bumper beama) Kinetic energy dissipated, b) strain energy absorbed

In *Figure 15* and *Figure 16* displacement vs time for both hollow and solid bumper beam along the axis of application of velocity has been shown respectively. The slope of the displacement vs time graph gives the average velocity change occurring as the two bumpers beams are deformed. The data values are plotted after the bumper has made contact with the wall, thus would show which bumper decelerates faster. For the hollow bumper beam, the change in velocity that has occurred from 5ms to 10 ms is $\frac{-95.87481689-(-50.14866257)}{0.01-0.005}$ = (-9145.23) mm/s, and for solid bumper beam, the change in velocity that has occurred from 5ms to 10ms is $\frac{-151.3014374-(-89.24117279)}{0.01-0.005}$ = (-12412.05) mm/s, thus the change in velocity occurring in solid bumper beam is more than that of hollow bumper beam, thus after the impact the solid bumper beam deaccelerates quicker than hollow bumper beam, and for the rest of the time solid bumper achieves zero acceleration, that is it stops deforming. Hence we can say that the hollow bumper deforms for a longer time thus providing more safety to the vehicle. The stiffness of the bumper beams undergoing deformation can be found by conservation of energy.

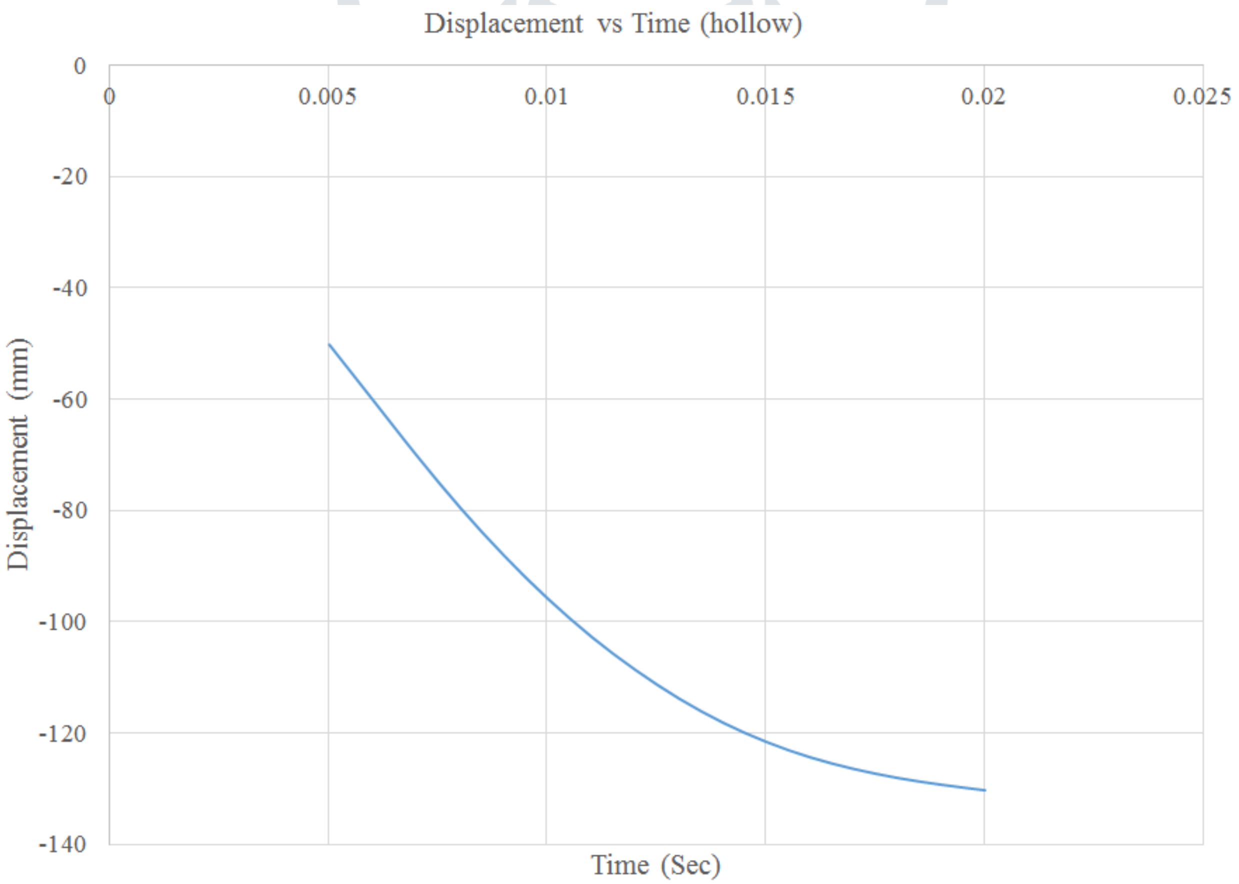


Figure 15: Displacement vs time for hollow bumper beam

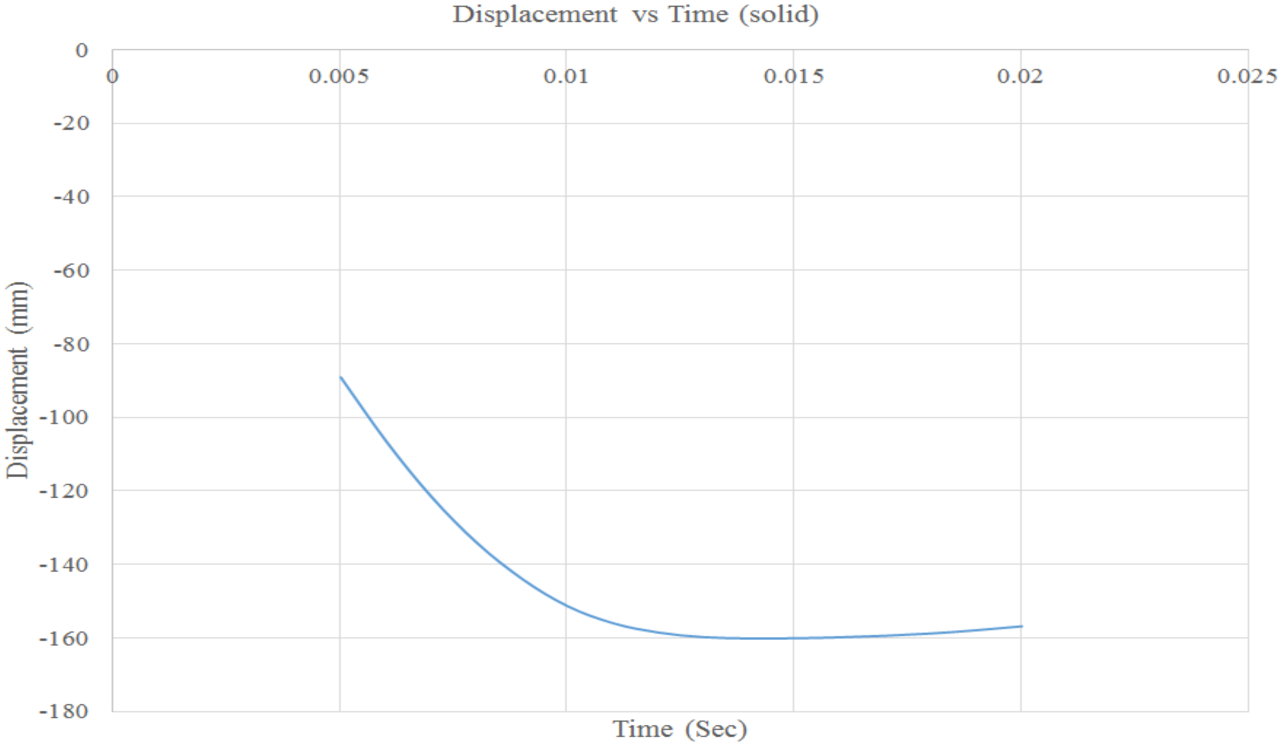


Figure 16: Displacement vs time for solid bumper beam

The kinetic energy of the beam is converted to potential energy as impact takes place. Considering V_{hollow} be the volume of hollow bumper beam, V_{solid} be the volume of solid bumper beam, the magnitude of volume for both the beams, has been found from creo cad software as 4705609 mm^3 and 5669060 mm^3 respectively. ρ is the density of the aluminium alloy with a value of 2.7×10^{-6} kg/mm^3. V is the applied velocity for both the bumpers. K_{hollow} be the stiffness of the hollow bumper beam and K_{solid} be the stiffness of solid bumper beam and δ_{hollow}, δ_{solid} be the deflection occurring for respective hollow and solid bumper beam respectively and the total deflection for hollow bumper beam was obtained as 130.4243011 mm and for solid bumper beam as 156.7642059 mm. Considering the energy balance for hollow bumper beam:

$$\frac{1}{2} x\ V_{hollow}\ x\ \rho x\ V^2 = \frac{1}{2} x\ K_{hollow} x\ \delta^2_{hollow}$$

$$\frac{1}{2} x\ 4705609\ x\ 2.7\ x\ 10^{-6} x\ (17777.778/1000)^2 = \frac{1}{2} x\ K_{hollow} x\ (130.4243011/1000)^2$$

K_{hollow} = 236057.34 N/m

The following equation can be written for solid bumper beam:

$$\frac{1}{2} x\ V_{solid}\ x\ \rho x\ V^2 = \frac{1}{2} x\ K_{solid} x\ \delta^2_{solid}$$

$$\frac{1}{2} x\ 5669060\ x\ 2.7\ x\ 10^{-6} x\ (17777.778/1000)^2 = \frac{1}{2} x\ K_{solid} x\ (156.7642059/1000)^2$$

K_{solid} = 196850.24 N/m

The stiffness of the hollow bumper beam is more as compared to solid bumper beam, thus it has comparatively less deformation (130.42 mm) as compared to solid bumper beam (156.76 mm), showing that the hollow bumper beam has the ability to absorb higher impact force than that of solid bumper beam for each meter of deflection.

CONCLUSION:

Frontal crash simulation of vehicle bumper beam was done to examine the deformation to the frontal area of the car in order to reduce injury risk and potential of safety. It is observed that during the frontal impact, the rate of stress generation is more for solid bumper beam than for hollow bumper beam and resistance to deformation response by solid bumper beam is faster than hollow bumper beam. The central area of the hollow beam is always less stressed and does not take part in impact resistance for longer period of time. The strain in the hollow beam mostly occurs at the edges. The hollow bumper's actuating tubes are less strained than solid bumper's actuating tubes. The hollow bumper thus absorbs energy for a longer time period without reaching its peak value unlike the solid bumper. Due to lower weight of hollow bumper beam, kinetic energy that is absorbed as strain energy is lower as compared to solid bumper beam as can be observed in both the energy curve and the von misses stress at 0.01 sec, where the stress value of the hollow bumper is 300 KPa less than the solid bumper and thus fails at a much later point. Due to low amount of localized molecular slip the hollow bumper shows some fluctuations while keeping an overall increasing trend due to the presence of high number unstrained molecules unlike the solid bumper. It is also found that the stiffness to deformation is more for hollow bumper beam than for solid bumper beam, thus more impact force is needed for hollow beam for deformation thus it has more strain energy of absorption than that of solid bumper beam.

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