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Crashworthiness Analysis of Grid Patterns of Impact Attenuator for Formula Student Vehicle

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Abstract – *In case Formula Student vehicle, where the design and manufacturing are primarily done by students, safety is given top priority. Impact Attenuator (IA) is one such structure, which is attached to the front bulkhead of vehicle to absorb the impact energy during the time of collision which ensures that the driver would be safe. Impact attenuator comes with several material and designs to absorb maximum energy with low level of deceleration. In case of material selection, aluminum is widely used to make IA, other material like impaxx 700 foam is also used to make light weight solid block impact attenuator. Safety of impact attenuator is validated by several criteria mentioned in FSAE rules. When aluminum is used for impact attenuators, the honeycomb structure is commonly employed because of its lightweight nature and exceptional energy absorption property due to its unique pattern. But there may be a chance that some other patterns could perform well than honeycomb and could employed in Impact attenuator. This paper focuses on FEA analysis of different type grid pattern and its effectiveness in energy absorption. The simulation is performed using LS-DYNA software which is widely used in crash simulation.*

Key Words: impact attenuator, honeycomb, plastic deformation, formula student

1.INTRODUCTION

In automotive sector, ensuring safety during high impact collision is a major concern. This is likely to occur in competitions like Formula Student (FS). Impact Attenuator is one such device which is engineered to absorb energy during impact by undergoing plastic deformation, thereby reducing the force transmitted to driver, ensuring his safety as well as preventing damage to vehicle components. IA is positioned on front bulkhead, which is attached along with anti-intrusion plate (Fig.1). Selection of material and design of impact attenuator must be done by engineering through specific requirements such as absorbing maximum energy, limiting peak deceleration experienced by the driver. The test condition as per [1] is in such a way that IA should be mounted on a 300kg vehicle and impacting a non yielding impact barrier with an impact speed of 7m/s. The deceleration should not be exceeding 20g average and 40g peak and the energy absorbed in this condition must meet or exceed 7350 J. For ease of access and use, most teams prefer to use impact attenuator made of foam material mainly impaxx 700 foam. Energy absorption and light weightness are key requirements for energy absorbing pads in industries [3]. Albak et al. [2] conducted the study on standard IA foam.[4] conducted the study on crashworthiness of polyurethane foam for impact attenuator using FEA method.

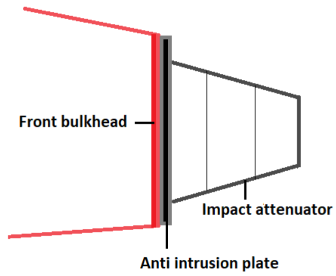

Fig -1: Arrangement of impact attenuator

IA is one such device which can be modified in wide variety of ways to improve performance. Laksmana Widi Prasetya et al. [5] designed crashworthy IA made from waste aluminium can based material. The experiment was conducted in both experimental and FEA method and found that cans with specific thickness and with proper arrangements can be used to make IA. [6] implemented a shoulder pattern in IA and studied its effects in anti intrusion plate. This is mainly conducted to avoid peak deceleration.[14], [15] studied the effect of composite materials to be used as impact attenuator. Attenuators also come with several shapes. For standard impact attenuator, it will be truncated pyramid with rectangular base, some forms elliptical shape with grids inside it. Most common IA which uses aluminium has several box structure attached one to other. Each designs provides its own significance during the crash. When it comes to material selection, apart from foam

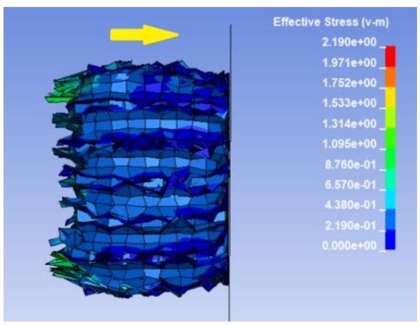

Fig -2: Using FEA method for IA impact model and composite types, aluminium is one of the widely used material for impact attenuator. Use is mainly due two factors- property of excellent energy absorption through plastic deformation and light weightness. The high strength to weight ratio also enables to reduce the overall load in the vehicle which is essentially focused by the teams.

Honeycomb structure is the prime structure type made from aluminium which is used to make IA. In several studies, honeycomb structure has proved to be excellent energy absorber. [7] conducted experiments with lowest mass and highest energy absorption combination. Due to unique pattern of honeycomb, overall mass of attenuator can be reduced without compromising the material. [8] made IA with sandwiched panel and aluminium inner sheets along with honeycomb structure for each units and analysed the effect of dynamic loading in it. Qiang Chen et al.[9] the modified structure of honeycomb and how it functions better than conventional one by studying uniaxial compression. The hexagonal structure results in collapsing through buckling or folding of cell wall during deformation. The pattern is also made to deform the structure continuously without concentrating the stress to particular point. The compression occurring during impact also absorb energy and distribute the stress to attached cells. [10] shows how the deformation of cell in origami model could influence the energy absorption characteristics.

Eventhough grid pattern with honeycomb structure gained wide popularity due to several experiments and positive test data, there may be chance that some other structures may perform more effectively than honeycomb structure. This paper focus on energy and deceleration study three different grid pattern for impact attenuator - honeycomb grid, square grid and triangular grid. The study also aims to find the best pattern structure to be implemented in IA. Due to meshing limitations and extended running times, the impact attenuator analysis does not done by choosing the baseline conditions for dimensions, energy absorption, and deceleration as specified in the FS rulebook [1]. Instead, all three structures are simulated under uniform of conditions that are more manageable and simplify the simulation process. Entire simulation is performed using LS DYNA (Fig.2).

2.MATERIAL AND STRUCTURE

The material model selected was aluminium alloy 6061 T6 known for its high energy absorption capability. The material is widely used in aerospace and automotive sector. For different grid pattern, the material with 0.6mm thickness is selected which indicates the material space between two cells in the structure. The baseline dimension for honeycomb cell was selected as 6.8mm (Fig.3). Such small dimension in cell structure helps to integrate more material which can absorb energy to deform plastically and at the same time maintaining structural rigidity. In case of square cells, each side is taken as 6.8mm, spaced equally at 0.6mm thickness to form final structure (Fig.4). In triangular cells, equilateral triangle is considered where length of each side is 6.8mm (Fig. 5).

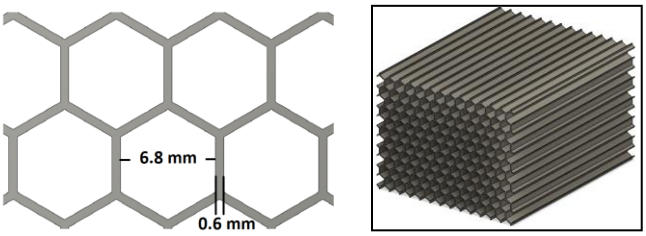

Fig -3: IA with honeycomb grid pattern

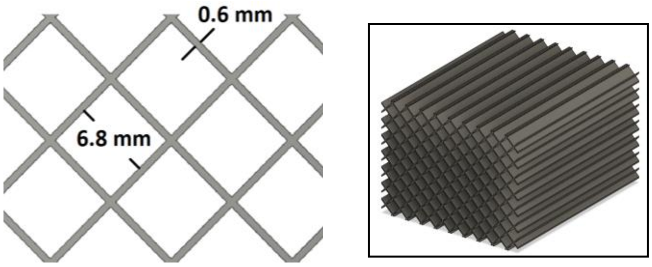

Fig -4: IA with square grid pattern

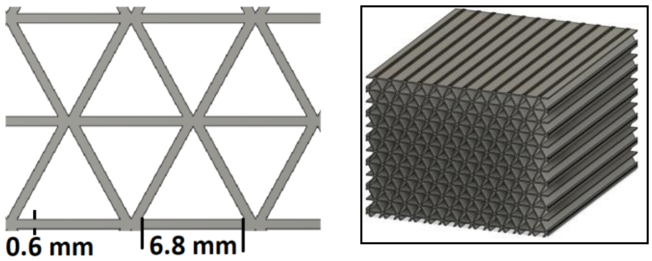

Fig -5: IA with triangular grid pattern

The overall dimension of the structure is considered as 100mm x 75mm x125mm, it is important to note that this is not standard dimension as referred in the FS rule book. Dimension is reduced to this value by maintaining aspect ratio with original one inorder to reduce the simulation complexity and time. Since the study is a comparison between different structures, the above mentioned dimension performs well in simulation. The solid model was designed in Fusion 360 software and then downloaded in iges format to import to LS DYNA.

3.METHODOLOGY

Grid model is drawn in fusion 360 and extruded to form particular solid shape. The model obtained is exported in iges format and uploaded to LS DYNA. Solid meshing is provided to the model with an element size of 11 along with layer option, which is essential to enable when simulating materials having thickness that needs to be accurately represented. From the front end of the IA to a distance of 50mm, a rectangular shell was modelled using "Shell 4N" from shape mesher option. The shell was modelled to represent the rigid wall on which the IA will impact to achieve the simulation result. The mesh was done in such a way that 10 vertical and 10 horizontal lines divides the rectangle into smaller square sections.

Then comes the crucial part of material selection for both IA and rigid wall. In case of rigid wall, it won't be a concern because the material used does not influence a lot since the wall is assumed to be stationery and will be constrained in all direction. But giving input of exact material properties to IA was crucial part. It is important to define curve section based on stress strain graph [12] for 6061 T6. Defining curve enables software to understand the material's nonlinear behaviour and accurate response to loading condition. Since the absorption of energy takes place in plastic region, curve definition is very important. Under material definition section, the material category assigned to model was "MAT_024_PIECEWISE_LINEAR_PLASTICITY", a model that can predict material behaviour for a wide range of deformation including elastic and plastic region. Since aluminium is an elastoplastic material, this material property is the best suits for it. In case of rigid wall, material property was assigned as steel. The thickness of rigid wall was made as 1mm.

Defining boundary condition is important to study the impact result. The movement of IA was restricted in all direction except in X axis. In case of rigid wall, the movement is restricted in all direction. Constraining rigid wall in all direction is necessary to give baseline for simulating all three structures. Total mass of 300 kg is attached to rear side of IA to ensure that the body have sufficient momentum and have enough energy during the time of collision. "AUTOMATIC SURFACE TO SURFACE CONTACT" was defined to detect contact surfaces and their interactions which results in accurate analysis. The velocity in x direction was defined as 15m/s which will exert sufficient energy during collision.

4.RESULT

The simulation is performed for an endtime of 15 seconds and two results are plotted which is necessary to compare the performance of structures.
(i) Internal Energy vs time
(ii)Acceleration

In case of honeycomb structure, the energy absorption is found to be maximum with a value of with a value of 36742 J (Fig.6). The pattern of honeycomb structure allows it to deform in specific manner allowing efficient distribution of force between cellular structure. More deformation by buckling occurs in the peripheral region than in central part (Fig.12). When the impact force first applied on grid structure, the walls of hexagonal cells experiences compression. The controlled collapsing ensures that energy is absorbed uniformly which is clearly depicted in the constant slope of internal energy vs time graph. The deceleration value obtained is 422 m/s^2 (Fig.7) which is lowest as compared to deceleration of other structures.

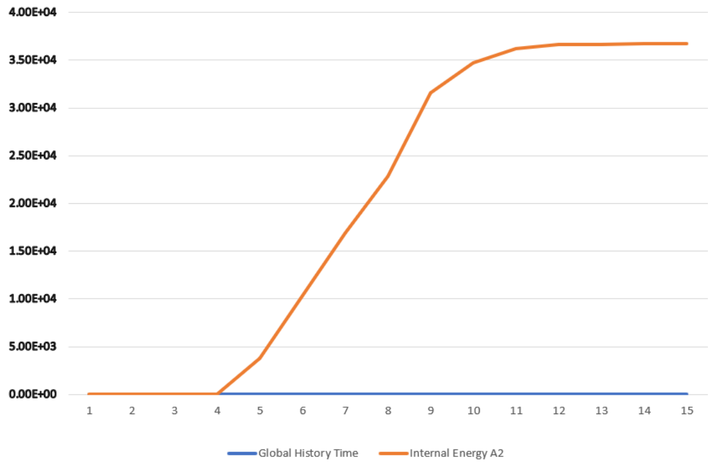

Fig -6: Internal energy vs Time graph of honeycomb model

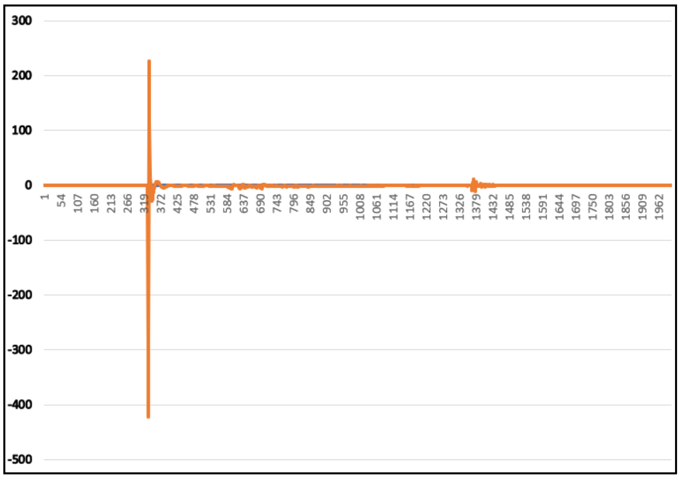

Fig -7: Acceleration graph of honeycomb model

Square grid pattern comes in the second position for absorbing energy, the maximum energy absorbed is 28956 J (Fig.8). The result obtained has a significant difference from that of honeycomb structure. The deceleration value obtained is 497 m/s^2(Fig.9). In case of square grid, it undergoes plastic deformation by elongation of square structure to parallelogram or trapezoidal shape (Fig 13). Compared to honeycomb geometry, the deformation is more in square pattern but the energy absorption is less.

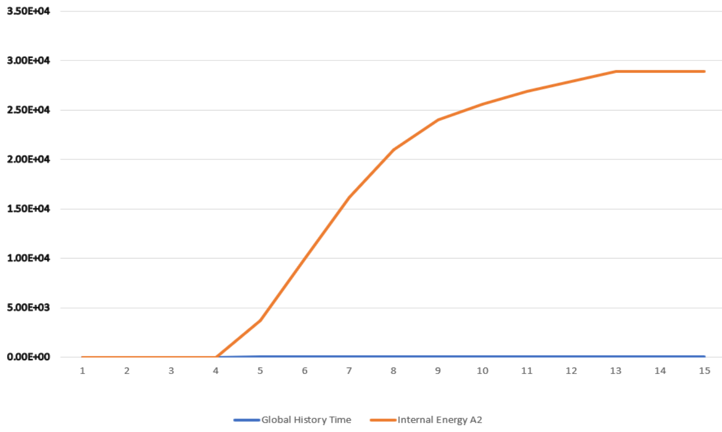

Fig -8: Internal energy vs Time graph of square model

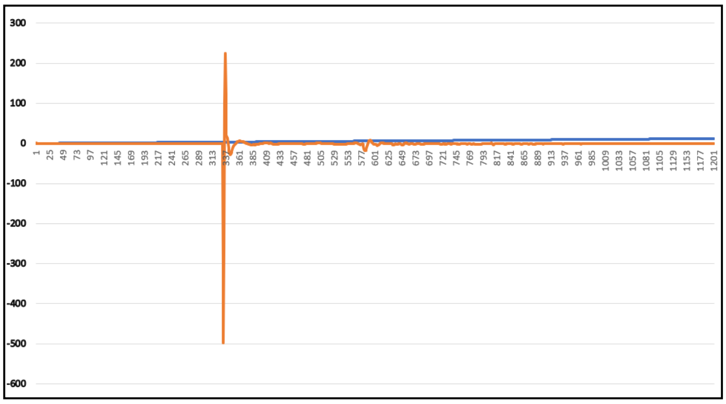

Fig -9: Acceleration graph of square model

Triangular grid pattern has least energy absorption and highest deceleration value, clearly indicating that it cannot be used for the purpose of impact attenuator. The energy absorbed is very low with value of 15122 J(Fig.10) and deceleration remains very high with value of 537 m/s^2. A high deceleration value is not desirable as a characteristic of the impact attenuator.

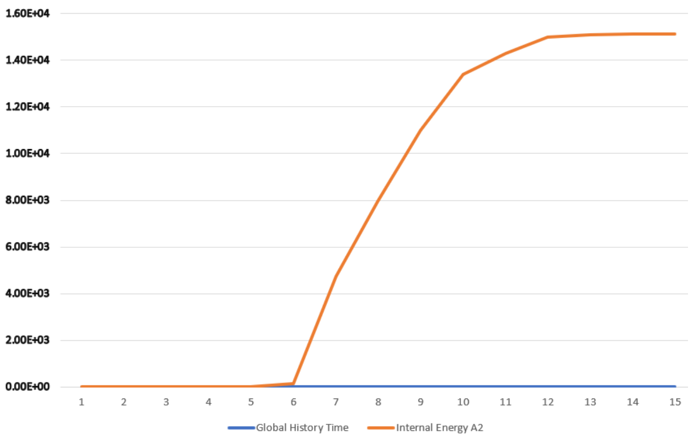

Fig -10: Internal energy vs time of triangular model

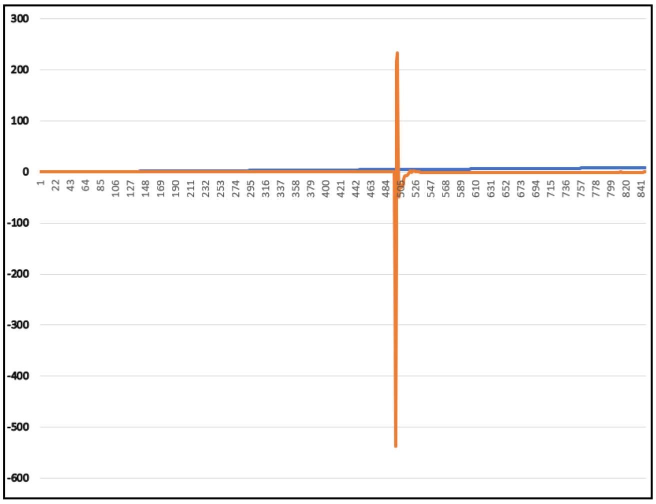

Fig -11: Acceleration graph of triangular model

Triangle is the strongest and stiff shape which makes the entire structure more rigid and less vulnerable to deformation under impact (Fig 14). Due to the constrain of triangular shape, instead of significant plastic deformation, the structure undergoes fracture.

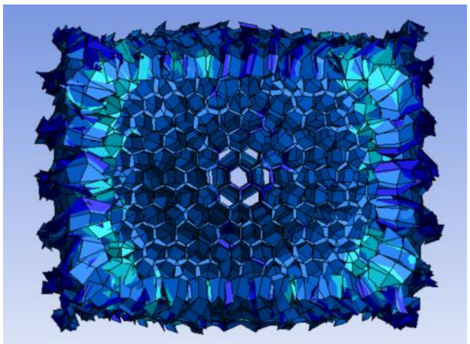

Fig -12: Deformation of honeycomb model after impact (front view)

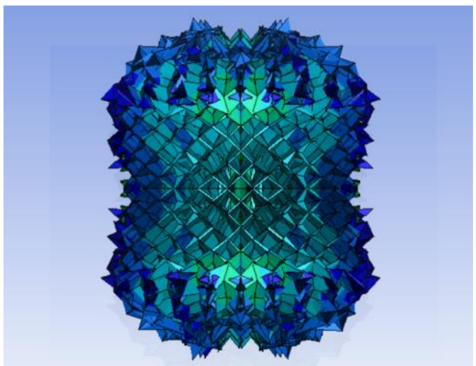

Fig -13: Deformation of square model after impact (front view)

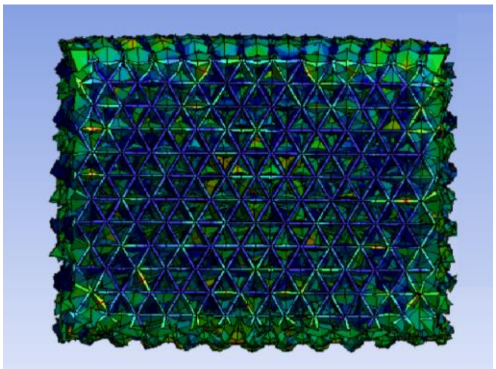

Fig -14: Deformation of triangular model after impact (front view)

5.CONCLUSION

The results obtained from analysis aligns with findings of other researchers confirming that honeycomb structures are most suitable for impact attenuator. It owns the highest energy absorption value with lowest value of deceleration which is crucial for crashworthy impact attenuators. Honeycomb structure effectively distribute impact force and undergo plastic deformation without concentrating stress to localised region, allowing greater absorption of energy with minimal deceleration. While square patterns absorb some amount of energy, they won't match with capability of honeycomb pattern. On the other hand, triangular geometry behaves differently. Due to stability of triangular structure, they resist plastic deformation, leading to low resilience value which indicates that energy from impact is not absorbed effectively. The findings support the effectiveness of honeycomb structures over other patterns and will be useful for guiding future research and development in improving the designs of impact attenuator for FS vehicles.

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