CRASH BEHAVIOR AND ENERGY ABSORPTION CHARACTERISTICS OF THIN S-SHAPED LONGITUDINAL MEMBERS

Mathapati Shivaputra[1]*, Raj Kumar Pittala[2]

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ABSTRACT

Vehicle accidents are happening every day. Most drivers are convinced that they can avoid such Trouble some situations. Nevertheless, we must take into account that ten thousand dead and hundreds of thousands to million wounded each year. These numbers call for the necessity to improve the safety of automobiles during accidents. Hence the main aim of this project is to conduct finite element analysis and to optimize the design and energy absorption of S-shaped longitudinal member having different cross section such as square, square with inner stiffener and square with double inner stiffener. The S-shaped longitudinal member is made up of Aluminum grade 6063-T5. For Aluminum grade 6063-T5 material having square with double inner stiffener cross section absorbing maximum energy we conclude that square with double inner stiffener cross section is very good at safety of the structure and operator compartment of vehicle.

Keywords: Finite Element Analysis, S-Shaped longitudinal member, Aluminium Grade 6063-T5, Square, Square with Stiffener.

[1*]Research Scholar, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Guntur-522502, Andhra Pradesh, India.
[2]Assistant Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Guntur-522502, Andhra Pradesh, India.

***Corresponding Author:** Mathapati Shivaputra
*[1]Research Scholar, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Guntur-522502, Andhra Pradesh, India.Email:shivaputra.vm@gmail.com

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1. INTRODUCTION:

Crashworthiness is an accident in which a moving vehicle hits something and is damaged or destroyed. Or the capability of vehicles structure to absorb there energy is called as crashworthiness. At present days lot of peoples (around 60,000) die due to vehicle to vehicle frontal collisions [1]. The vehicle should be designed or modified such that, structure as to absorb impact energy in a controlled manner.

Crashworthiness is the ratio of the mean crush(S) to the density of the composite material (D) ES=Mean crush stress/Density of the composite material S/D. Vehicles design engineering should keep in mind that while designing of vehicles the structure of vehicles should absorb the maximum energy during impact [2]. In present days accidents happens every hour around the world and most of these are very dangerous. Frontal impact crash is one of the most serve crash scenario. A scan of literature survey has been done from the past few decades Crash Behavior and Energy Absorption Characteristics of thin S-shaped Longitudinal Members and is discussed as below.

Ashwani Mittal [3] et al. carried out the Explicit Dynamic Frontal Crash Analysis of an All-Terrain Vehicle Roll Cage Explicit Dynamic Frontal Crash Analysis of an All-Terrain Vehicle Roll Cage. It is found that Von Mises stresses of the roll cage model except a joint of Side Impact Member is lower than the permissible limit. The roll cage can effectively protect the driver from any injury during the event of a frontal crash of the vehicle. Sobhan Esmaeili-Marzdashti [4] et al. carried out the Crashworthiness Analysis of S-Shaped Structures under Axial Impact Loading. The multi-cell S-shaped members were found to perform better than single-cell ones in terms of crashworthiness. In addition, the multi-cell S-rail with decagonal cross-section was found as the best energy absorber, and also the S rail having the same inner and outer tube with decagonal cross-section displayed desirable crashworthiness performance.

N. Baaskaran [5] et al. studied the Quasi-Static Crushing and Energy Absorption Characteristics of Thin-Walled Cylinders with Geometric Discontinuities of Various Aspect Ratios. The presence of cut-out with higher major axis length reduces the maximum peak force, causes the greater crushing deformation of thin-walled structures. The location of cut-out can drastically influences the energy absorption and buckling characteristics of the thin-walled tubes. Yongjie Zhang [6] et al. carried out an Analysis of Crash Characteristics of Hydrogen Storage Structure of Hydrogen Powered UAV. It is found that the initial cracks of the tank body under various load conditions are mostly concentrated in the middle of the tank body. The results showed that when the deformation of the hydrogen storage structure exceeds 50 mm, and the strain exceeds 0.8, an initial crack will appear at this part of the hydrogen storage structure.

M A Choiron [7] et al. carried out an Analysis of multi-cell hexagonal crash box design with foam filled under frontal load model. The simulation results show that the highest energy absorption value is the multi-cell hexagonal outer foam filled crash box with that Ea is 30,606 kJ. There is a significant difference between the multi-cell hexagonal crash box model with foam filled and without foam filled. The addition of foam filled on the multi-cell hexagonal crash box has important effect to improve energy absorption performance. Lianman Xu [8] et al. carried out an Analysis of U-Shaped Steel Failure Characteristics in Rock Burst Roadway and Design of Stable Structure and Constant Resistance O-Shed. From the numerical simulation results, it can be seen that the load-bearing performance and energy absorption of the U-shaped steel support with a uniform load are better than those of the U-shaped steel support with a centralized load. Yong Zhang [9] et al. studied the Characteristics of Energy Dissipation in T-Shaped Fractured Rocks under Different Loading Rates. It is found that with the increase in loading rate, the total absorbed energy and elastic energy at the peak point of the T-fractured rock specimen increase, but the dissipated energy decreases. The increase in loading rate leads to an increase in the elastic energy and a decrease the dissipated energy at the peak point of the T-shaped fractured rock specimen at a maximum value of 90%. Septiana Widi Astuti [10] et al. studied the Comparison of Energy Absorption and Pattern of Deformation Material Crash Box of Three Segments with Bilinear and Johnson Cook Approach. The findings showed that the value of energy absorption in the crash box material with bilinear approach was higher of 8954 J compared to the crash box with the Johnson cook approach of 8859 J. The patterns of deformation of bilinear crash box tended to form concertina and mixed patterns (concertina+diamond).

From the above literature survey it is found that no research has been done on the Crash Behavior and Energy Absorption Characteristics of thin S-shaped Longitudinal Members. Hence the main aim of this project is to conduct finite element analysis and to optimize the design and energy absorption of S-shaped longitudinal member having different cross section and made up of Aluminum grade 6063-T5 material.

2. EXPERIMENTAL DETAILS

A Here the energy absorbing member is come up in many designs but in this project we particularly considering the S-shaped member keeping in mind of design and weight of the structure [11]. The S-beam structure has been modeled in cad (CATIA-V5) having different sections such as square, square with inner stiffener and square with double inner stiffener having 3mm thickness. For the same models FE model were generated using HYPERMESH.

The steps involved in FE models as follows.

CAD model was imported in HYPERMESH and necessary geometry cleanup was done using quick edit panel in HYPERMESH, Mid surface was excreted and depends upon the configuration of geometry elements types are classified as 0D, 1D, 2D, 3D. As per our geometry configuration we choose 2D elements (shell meshing) for FE modeling. Shell meshing was carried out using manual meshing as well as auto meshing commend. Such as rolled, spline, line rack drag and auto mesh. And as per sectional properties in the geometry we assigned sectional properties using card image (sectional shell) and element formed two (el form) was used to assigned thickness.

Material properties was assigned to the FE Model using material card as MAT24 in this card relevant material properties such as stress and strain structural data, Young's modulus, Poisson's ratio and Yield strength was defined And boundary condition was applied as per paper description to the S beam one side of S beam was fixed in all degree of freedom and rigid wall was created then defined contacts (single surface) and rigid wall was considered as master and beam was consider as slave and velocity 2 m/s was given to the rigid wall. Then for output results are defined control card such as, GLSTAT, MATSUM, NODOUT, ELOUT, RWFORC, NCFORC, SLEOUT, SEFORCE AND SCEFORCE. These above shown cards are very useful to plot post processing. And LS-Dyna solver deck was exported and fired a run and what the results are getting post processed using LS Post [12].

Due to increasing cost on conducting real-time crash simulations, CAE tools are used in automotive industry. As a result, product development cost has reduced. The capability of CAE tools these days has progressed to the point where much of the design verification is now done using computer simulations rather than physical prototype testing.

2.1Modelling

Geometry

The Propeller shaft considered for the analysis is shown in the below Figure 1. The geometry parameters are listed in the Table 1.

Table 1 Geometry Parameters

Geometric Parameters		
Parameters	Values	Unit
Length	1000	Mm
Width	80	Mm
Thickness	3	Mm

The key parameters include impact velocity, cross-sectional shape, material type, thickness and added stiffeners [13].

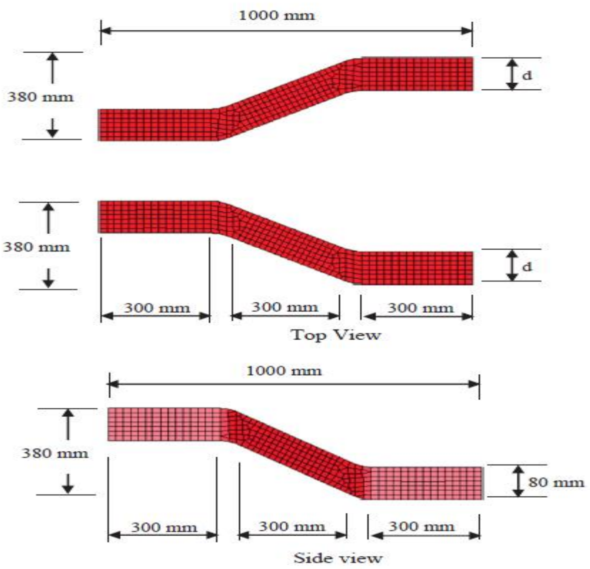


Fig. 1 Propeller shaft

2.2 Mechanical properties for S-Shaped Longitudinal Member

Define materials:

A material is defined by its material constants. Each element has to be assigned with appropriate material constants to obtain exact results.

Aluminum grade 6063-T5

The linear Aluminum grade 6063-T5 material properties used for the analysis and properties are listed in the below Table 3.4. The Stress and Strain of Aluminum grade 6063-T5 is shown in the Table 2.

Table 2 Material properties of Aluminum grade 6063-T5

Parameter	Values	Units
Young’s Modulus (E)	68.9	GPa
Poisson’s ratio	0.33	
Density	27	Kg/m3
Yield stress	145	MPa

Properties

1. Strength to weight ratio is high.
2. Stiffness to weight ratio is high.
3. Impact resistance is high.
4. Better fatigue resistance
5. Good corrosion resistance
6. Good thermal conductivity.
7. High damping capacity.

2.3 Models of S-Members

The S-beam structure has been modeled in cad (CATIA-V5) having different sections such as square, square with inner stiffener and square with double inner stiffener having 3mm thickness.

Figure 2 shows Square S-shaped member. For the same models FE model were generated using HYPERMESH.

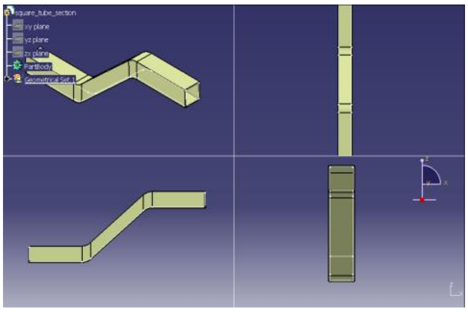


Fig. 2 Square S-shaped membe

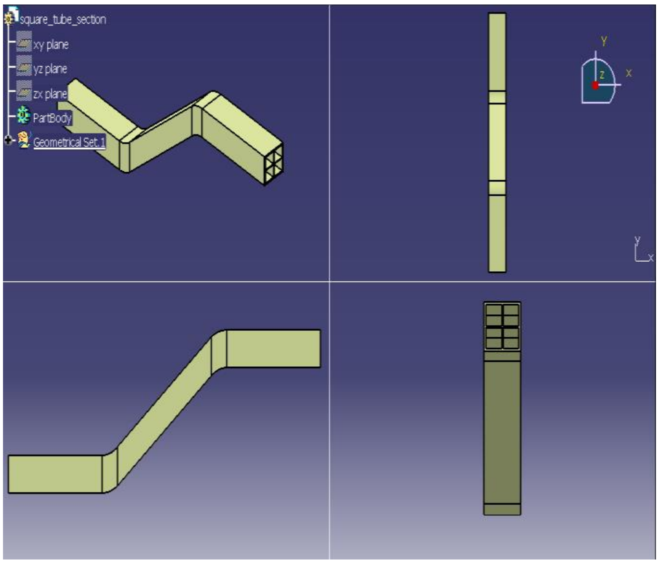


Fig. 3 Square with inner stiffener S-shaped member

Figure 4 shows the square with double inner stiffener S-shaped member.

2.4 Hypermesh Models

Finite Element Model of square S-shaped longitudinal member is shown in the below Figure 5. The global element size of 3 mm is used. The SECTIONAL SHELL 2D element is used for the analysis.

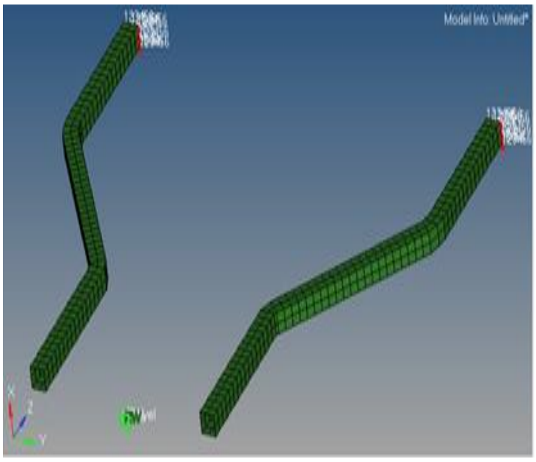


Fig. 4 Square with double inner stiffener S-shaped memb

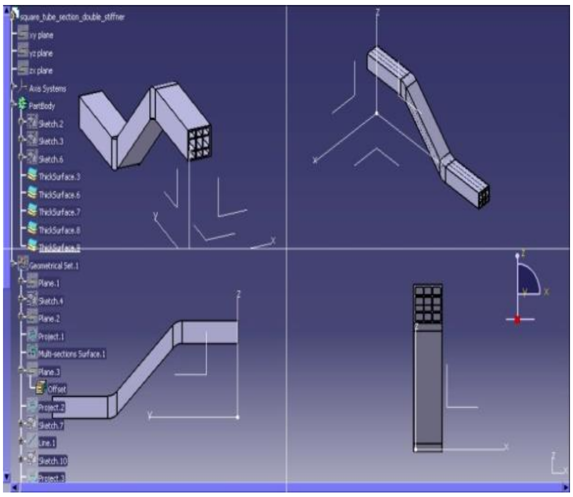


Fig. 5 Square S-shaped member

Finite Element Model of square with inner stiffener S-shaped longitudinal member is shown in the below Figure6. The global element size of 3 mm is used. The SECTIONAL SHELL 2D element is used for the analysis [14].

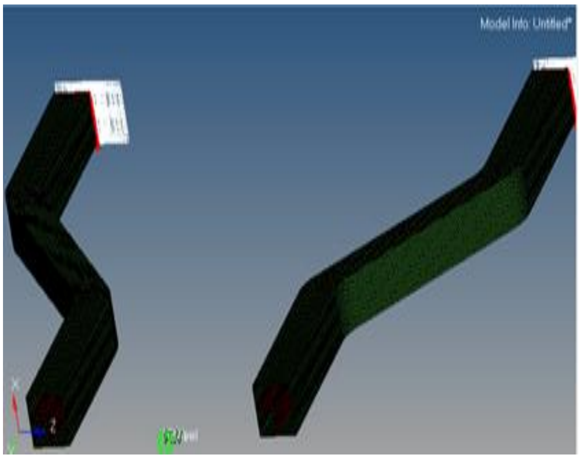


Fig. 6 Square with inner stiffener S-shaped member

Finite Element Model of Square with double inner stiffener of S-shaped longitudinal member is shown in the below Figure 7. The global element size of 3 mm is used. The SECTIONAL SHELL 2D element is used for the analysis [93].

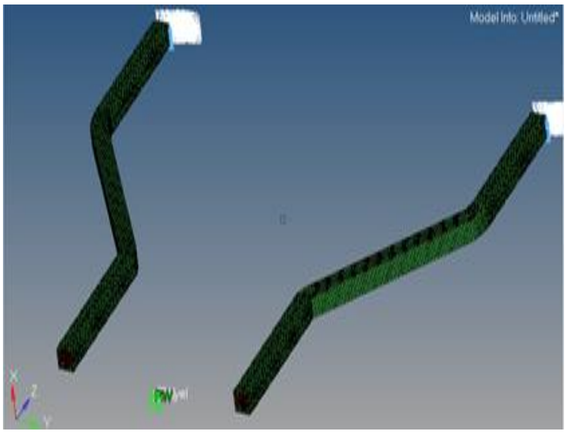
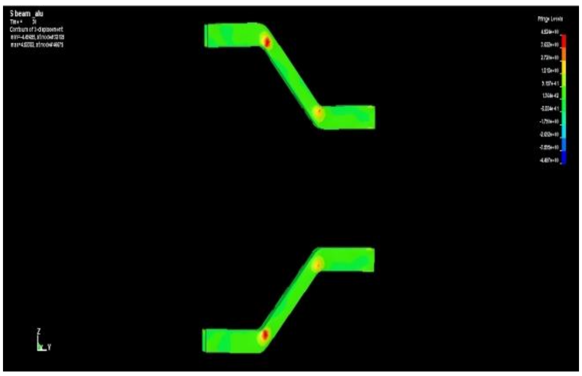


Fig. 7 Square with double inner stiffener S-shaped member

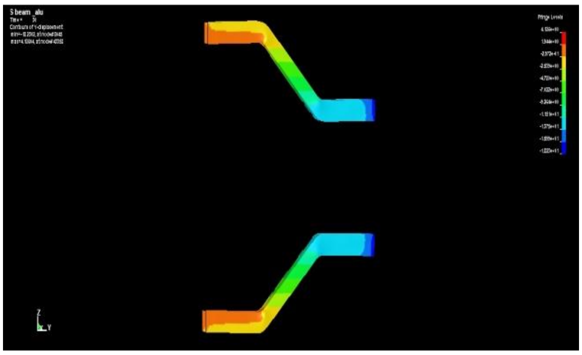
3. RESULTS AND DISCUSSION

3.1 Square Aluminum displacement in X and Y direction

3.1.1 Displacement Plot



(a)



(b)

Fig. 8 (a) and (b) Square Aluminum S-member displacement

The X-displacement plot of the Square Aluminum S-shaped longitudinal member is shown in the above Fig. 8 (a). The maximum displacement is 4.52 mm at the corner. The Y-displacement plot of the Square Aluminum S-shaped longitudinal member is shown in the above Fig. 8 (b). The maximum displacement is 4.18 mm at the corner [15].

3.1.2 Global energy Plot

Figure 9 shows Kinetic energy, Internal energy and Total energy of Square Aluminum S-member. Table 3 shows Global Energy plots.

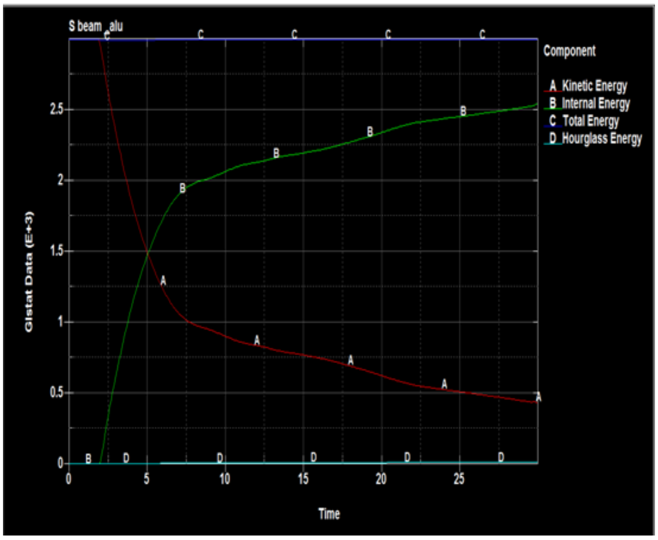


Fig. 9 Kinetic energy, Internal energy and Total energy of Square Aluminum S-member

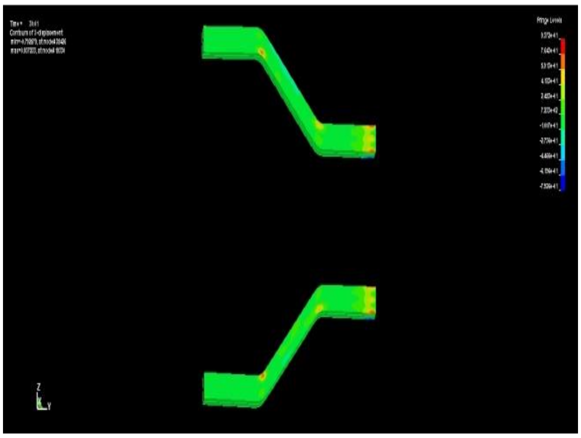
Table 3 Global Energy plots

Square Aluminum S shaped-member	
kinetic energy	internal energy
3.0	2.51

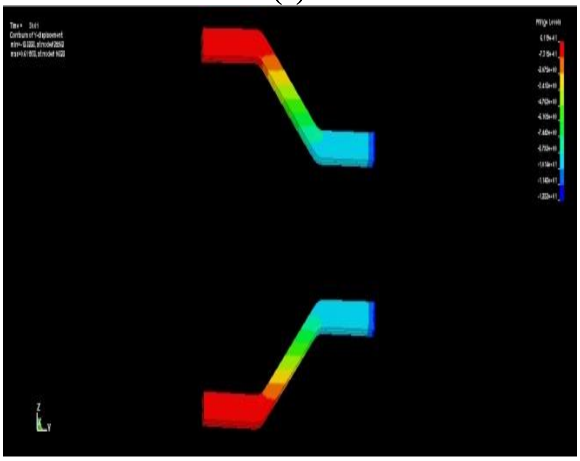
From the above Global Energy plots we conclude that post-processing first checked and the Energy plots which consists of internal, kinetic and total energy plots. As we can see that kinetic energy reduces the internal energy absorbed increases and the total energy plot remains constant [16].

3.2 Square Aluminum with inner stiffener displacement in X and Y direction

3.2.1 Displacement Plot



(a)



(b)

Fig.10 (a) and (b) Square Aluminum with inner stiffener S-member Displacements

The X-displacement plot of the Square Aluminum with inner stiffener S-shaped longitudinal members is shown in the above Fig. 10 (a). The maximum displacement is 0.93 mm at the corner. The Y-displacement plot of the Square Aluminum with inner stiffener S-shaped longitudinal members is shown above in the above Fig. 10 (b). The maximum displacement is 0.61 mm at the corner [17].

3.2.2 Global energy Plot

Figure11 shows the Kinetic energy, Internal energy and Total energy of Square with inner Stiffener Aluminum S-member. Table 4shows Global Energy plots.

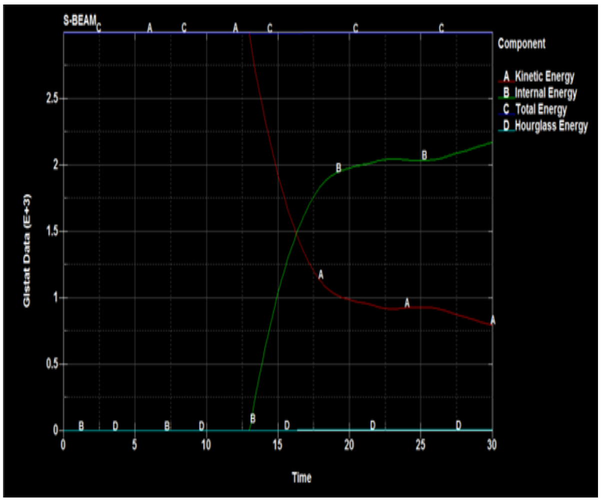


Fig. 11Kinetic energy, Internal energy and Total energy of Square with inner Stiffener Aluminum S-member

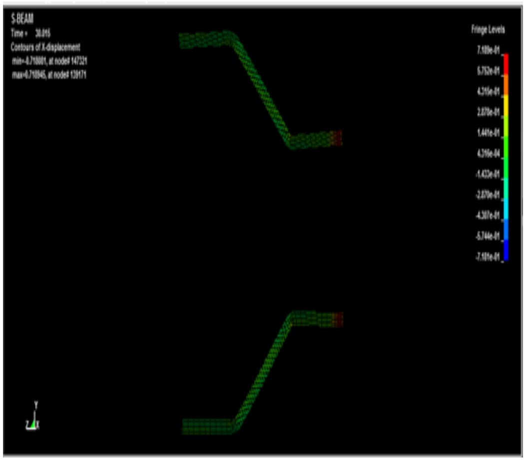
Table 4 Global Energy plots

Square Aluminum with inner stiffener S shaped-member	
kinetic energy	internal energy
3.0	2.2

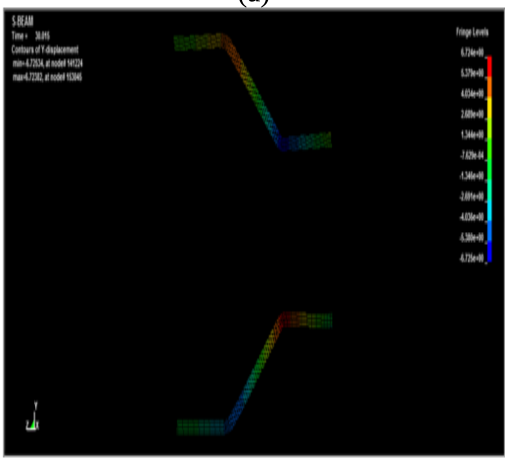
From the above Global Energy plots we conclude that post-processing first checked and the Energy plots which consists of internal, kinetic and total energy plots. As we can see that kinetic energy reduces the internal energy absorbed increases and the total energy plot remains constant [18].

3.3 Square Aluminum with double inner Stiffener displacement in X and Y direction

3.3.1 Displacement Plot



(a)



(b)

Fig. 12 (a) and (b) Square Aluminum with double inner Stiffener of S-member displacement

The X-displacement plot of the Square Aluminum with double inner Stiffener S-shaped longitudinal members is shown in the above Fig. 12 (a). The maximum displacement is 0.71 mm at the corner [19]. The Y-displacement plot of the Square Aluminum with double inner Stiffener S-shaped longitudinal members is shown above in the above Fig. 12 (b). The maximum displacement is 6.73 mm at the corner.

3.3.2Global energy Plot

Figure13 shows the Kinetic energy, Internal energy and Total energy of Square with double inner stiffener Aluminum S-member. Table 4 shows Global Energy plots.

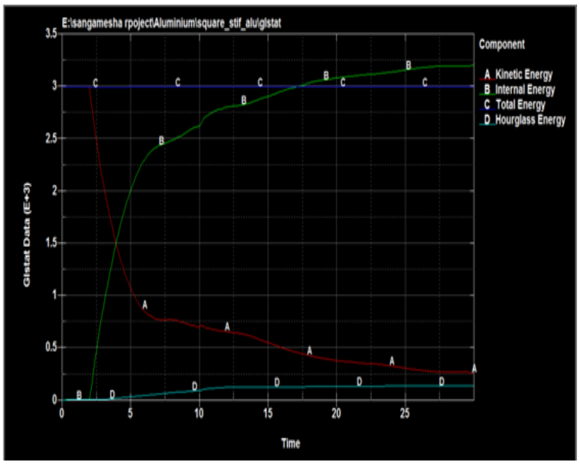


Fig. 4.20 Kinetic energy, Internal energy and Total energy of Square with double inner Stiffener Aluminum S-member.

Table 4Global Energy plots

Square Aluminum with double inner Stiffener S shaped-member	
kinetic energy	internal energy
3.0	2.4

From the above Global Energy plots we conclude that post-processing first checked and the Energy plots which consists of internal, kinetic and total energy plots. As we can see that kinetic energy reduces the internal energy absorbed increases and the total energy plot remains constant [20].

3. CONCLUSION

The main aim of this project is to conduct finite element analysis and to optimize the design and energy absorption of S-shaped longitudinal member having different cross section such as square, square with inner stiffener and square with double inner stiffener and made up of Aluminum grade 6063-T5. For Aluminum grade 6063-T5 material having square with double inner stiffener cross section absorbing maximum energy we conclude that square with double inner stiffener cross section is very good at safety of the structure and operator compartment of vehicle.

REFERENCES

1. A. Porwal, A. Tripathi, and P. Krishnasamy, Frontal Crash Worthiness Performance of Bi-Tubular Corrugated Conical: Structures under Axial Loads at Low Velocity. 2020.
2. K. D. Karantza, D. E. Manolakos, "Crashworthiness analysis of square aluminum tubes subjected to oblique impact: Experimental and numerical study on the initial contact effect," Metals, vol. 12, no. 11, 2022, p. 1862.
3. Ashwani Mittal, Anil C. Mahato, Mukesh Sharma, Explicit Dynamic Frontal Crash Analysis of an All-Terrain Vehicle Roll Cage, Applications of Modeling and Simulation, 7, 2023, 85-92.
4. Sobhan Esmaeili-Marzdashti, Sadjad Pirmohammad, Sareh Esmaeili-Marzdashti, Crashworthiness Analysis of S-Shaped Structures Under Axial Impact Loading, Latin American Journal of Solids and Structures 14, 2017, 743-764, http://dx.doi.org/10.1590/1679-78253430.
5. N. Baaskaran, K. Ponappa, S. Shankar, Quasi-Static Crushing and Energy Absorption Characteristics of Thin-Walled Cylinders with Geometric Discontinuities of Various Aspect Ratios, Latin American Journal of Solids and Structures, September 2017,1767-1787, DOI: 10.1590/1679-78253866.
6. Yongjie Zhang, Songyuan Wang , Bo Cui and Nuo Zhang, Analysis of Crash Characteristics of Hydrogen Storage Structure of Hydrogen Powered UAV, Aerospace 2022, 9, 687, 1-15, https://doi.org/10.3390/aerospace9110687.
7. M A Choiron, Analysis of multi-cell hexagonal crash box design with foam filled under frontal load model, Journal of Physics: Conference Series, IOP Publishing,1446 (2020) 012022, 1-7, doi:10.1088/1742-6596/1446/1/012022.

8. Lianman Xu, Jinzhu Zhang, Rixin Guo, Analysis of U-Shaped Steel Failure Characteristics in Rock Burst Roadway and Design of Stable Structure and Constant Resistance O-Shed, Advances in Civil Engineering, Volume 2023, Article ID 9246508, 1-14, https://doi.org/10.1155/2023/9246508.
9. Yong Zhang, Lijia Zhong, Fan Pang, Characteristics of Energy Dissipation in T-Shaped Fractured Rocks under Different Loading Rates, Sustainability 2023, 15,13695, 1-20, https://doi.org/10.3390/su151813695.
10. Septiana Widi Astuti, Willy Artha Wirawan, Akbar Zulkarnain, Dedik Tri Istiantara, Comparison of Energy Absorption and Pattern of Deformation Material Crash Box of Three Segments with Bilinear and Johnson Cook Approach, Journal of Physics: Conference Series, IOP Publishing, 1273 (2019) 012078, doi:10.1088/1742-6596/1273/1/012078.
11. Faris M. AL-Oqla, "Effects of intrinsic mechanical characteristics of lignocellulosic fibres on the energy absorption and impact rupture stress of low density polyethylene biocomposites," International Journal of Sustainable Engineering, vol. 14, no. 6, 2021, pp. 2009-2017.
12. K.P. Wong, C.S. Hassan, P. Qiang, S.M. Sapuan, N.A. Aziz, and M.Y.M. Zuhri, "Crash behaviour of unidirectional oil palm empty fruit bunch fibre-reinforced polypropylene composite car bumper fascias using finite element analysis," Functional Composites and Structures, vol. 3, no. 4, 2021, p. 044001.
13. N. Yusof, S. Sapuan, M. Sultan, and M. Jawaid, "Conceptual design of oil palm fibre reinforced polymer hybrid composite automotive crash box using integrated approach," Journal of Central South University, vol. 27, no. 1, 2020, pp. 64-75.
14. X. Li, Y. Wang, X. Xu, X. Cao, and R. Li, "Energy absorption characteristics of crash box of new honeycomb core structure with foam-filled," International Journal of Automotive Technology, vol. 22, no. 1, 2021, pp. 221-230.
15. Kumar, A. P., Pradeep, C., Gupta, S. S. R., Krishna, G. V., & Harshavardhan, G. (2021). Impact loading behavior of woven glass fabric polymer composite bi-tubular square sections. Materials Today: Proceedings, 47, 6291-6295.
16. Hussain, N. N., Regalla, S. P., & Rao, Y. V. D. (2021). Study on influence of notch triggers on absorption of energy for composite automobile crash box under impact loads. Materials Today: Proceedings, 38, 3220-3231.
17. Ma, L., Liu, F., Liu, D., & Liu, Y. (2021). Review of strain rate effects of fiber-reinforced polymer composites. Polymers, 13(17), 2839.
18. Keni LG, Singh V, Singh N, et al. Conceptual design and analysis of a car bumper using finite element method. Cogent Eng., 8, 1976480, 2021.
19. Wang, H.T.; He, M.M.; Zhang, Z.Q.; Zhu, J.W. Determination of the constant mi in the Hoek-Brown criterion of rock based on drilling parameters. Int. J. Min. Sci. Technol. 2022, 32, 747–759.
20. Liu, Y.; Wang, E.; Jiang, C.; Zhang, D.; Li, M.; Yu, B.; Zhao, D. True Triaxial Experimental Study of Anisotropic Mechanical Behavior and Permeability Evolution of Initially Fractured Coal. Nat. Resour. Res. 2023, 32, 567–585.