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Design and Analysis of an Origami-based Impact Absorption Structure in Safety Helmets

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Abstract - *This paper aims and proposes for developing an impact absorption structure based on origami inspired structure using both the properties of flexibility and rigidity that the pattern provides. The geometry of material used to replace EPS foam is Miura-Ori pattern and Honeycomb pattern. The material used for testing is nylon because it has maximum plastic deformation in compared to other 3D printing materials and due to its high strength fibres and flexibility. Modelling and analysis of the matrix is done in SoildWorks. The paper provides analysis of matrix under drop weight impact test simulation. The outcome of project is to provide an alternative for impact absorption structure design which provides safer and efficient impact absorption in helmets.*

Key Words: Drop weight impact testing, Impact absorption structure, Origami, Miura-Ori structure, Honeycomb structure, Safety Helmets.

1.INTRODUCTION

Generally used impact absorption structure are made of polystyrene foams and polycarbonate shells which are responsible for most of the energy absorption and deformation during any impact. The energy absorption can be increased by increasing density and thickness of polystyrene. But with increase in thickness, the size of safety helmet increases which will not be accepted by customers. In some impact absorption structure the foam used is crushable but do not recover after impact. There are various origami pattern used in engineering application namely Yoshimura, Miura-Ori, Waterbomb, Diagonal, Ron Resch. The origami inspired structure chosen to replace foam in this project is based on Miura-Ori pattern combined to form a honeycomb structure .The energy absorption of this structure is high as compare to foam in impact absorption structure. Miura-Ori is widely used in engineering application due to its high stiffness to weight ratio, negative Poisson's ratio, and one degree of freedom. This unique property allows this pattern to absorb energy during impact [1]. Miura-Ori pattern can dissipate large amount of energy through plastic deformation and transverse shear deformation. Stacking of various Miura-Ori sheet and forming sandwich structure subjected to blast load performs better than honeycomb structure and many other origami structures. Various plane Miura-Ori sheet dimensions are studied [2]. The stacked matrix of the Miura-Ori pattern is analyzed under Drop weight impact testing to check the Impact absorption capacity of model.

The alternative structure can improve the life of impact absorption structure which is never used before. The work is to provide alternate design in form of matrix structure. In the following section the method used to develop the structure is described.

2. METHODOLOGY

2.1 Pattern Selection

Folding sheet to form 3D structure provides various enhanced structural properties. Due to symmetry in pattern the unit cell can be easily replicated to form a pattern. Combination of different folding and reverse folding at different creases and folds forms different structure such as Yoshimura pattern, Miura-Ori pattern, Diagonal pattern, Tachi–Miura pattern, Ron Resch pattern.

For this research we have selected Miura-Ori pattern because plane deformation Miura-Ori sheet has negative Poisson's ratio for in-plane deformation and positive Poisson's ratio for out of plane deformation and the folding motion has single degree of freedom due to which folding metamaterial can be machined into any shape and still motion is preserved[3]. The Miura-Ori core dissipates 123% more energy through plastic deformations and has 66% greater core efficiency than the honeycomb core for a pressure of 100 MPa . For a pressure of 300 MPa , the Miura-Ori core dissipates 7% more energy through plastic deformations. Therefore the loading intensity, the energy dissipated by the Miura-Ori core is larger than that by the honeycomb core. The Miura-Ori core dissipates on average, 23% or greater energy than the honeycomb core [2].

2.2 Design of Miura-Ori Sheet

The standard Miura-Ori pattern has unit cell is made up of four similar parallelogram. Various parameters required for designing of Miura-Ori were taken from reference [3]. For our design we have selected single unit of Miura-Ori sheet which is made up of side length 12mm, angle of folding is 60 degree and dihedral fold angle of 120 degree. The Miura–Ori sheet is designed in folded form. The thickness of sheet is 2 mm.

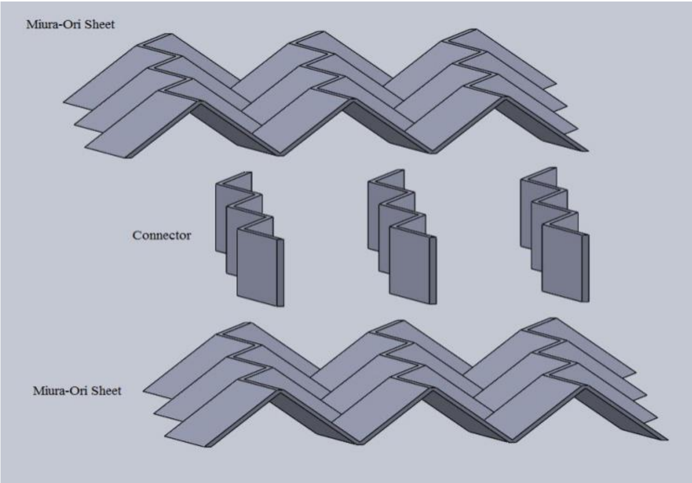

Fig -1: Miura-Ori sheets with connectors separately.

2.3 Formation of Matrix Structure

The pattern of Miura-Ori sheet is stacked vertically parallel to each other .The parallel sheet are connected by connectors. The resulted structure formed due to stacking and connecting has hexagonal shape due to which the properties of structure is enhanced in terms of stability. The matrix formed for drop test simulation is 100mm X 100mm X 31.18mm.

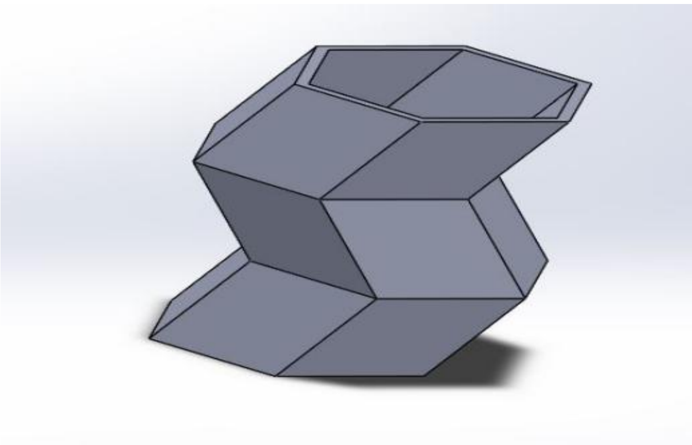

Fig -2: Unit Cell Design

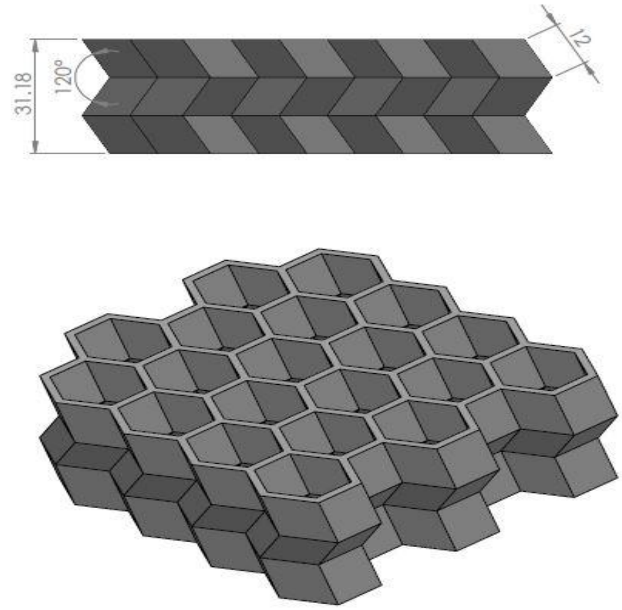

Fig -3: Matrix of Miura-Ori Designed Structure

2.4 Selection of Material

The main criteria to replace foam in safety helmets with new material should have higher impact absorption properties. Hence to replace the foam the material should have high strength to weight ratio. In order to recreate the structure using additive manufacturing technique there is limitation in material use. Most commonly used material for 3D printing is ABS plastic, PLA, Polyamide and Nylon. Out of these, Nylon shows highest energy dissipation in plastic deformations as compared to other 3D printing alternatives.

Table- 1: Material Properties

Properties	EPS Foam	Nylon
Density (kg/m^3)	1100	1140
Elastic Modulus (N/m^2)	2.65e+009	5.79e+008
Tensile Strength (N/m^2)	5.1e+007	2.78e+007

3. ANALYSIS

Generally impact absorption structure are tested for dynamic compression test with a drop tower. For testing under standard condition the total mass of impact absorption structure and headform combined used is 5 kg. The structure under test is sandwiched between two plates to ensure the uniform distribution of forces on the structure. The combination is dropped on an anvil at an impact velocity of 10 m/s, and assuming an impact time of 100 microseconds. A mesh element size of 3mm is used for the simulation. The displacement and deceleration is noted as result of experiment [4]. We tried to perform the same experiment with the designed matrix structure using SoildWorks. In SoildWorks simulations is done for EPS Foam, Honeycomb Structure and compared to our designed structure. The data such as von Mises stresses, displacement and acceleration of the headform are compared.

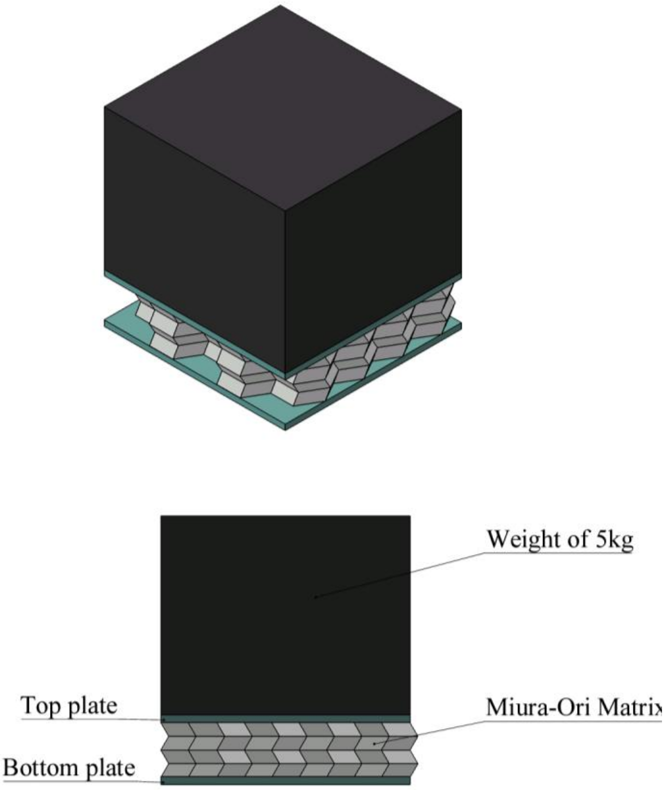

Fig -4: Drop test simulation setup

For comparing standard impact absorption structure, foam of EPS (Expanded Polystyrene) material is considered. For Miura-Ori material used is Nylon. For better understanding of our design efficiency we have also compared it with Honeycomb structure. Below are the output obtained from the drop test simulation performed on SoildWorks.

3.1 Analysis of EPS Foam

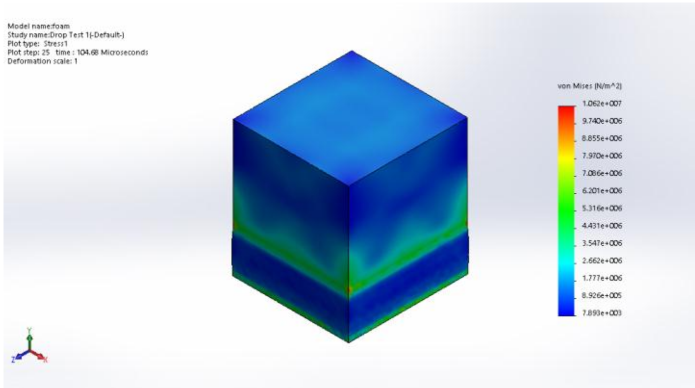

Fig -5: Von-Mises stress distribution in EPS Foam

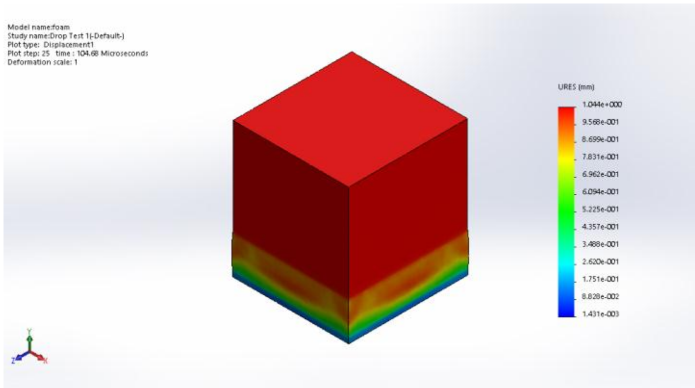

Fig -6: Displacement field in EPS Foam

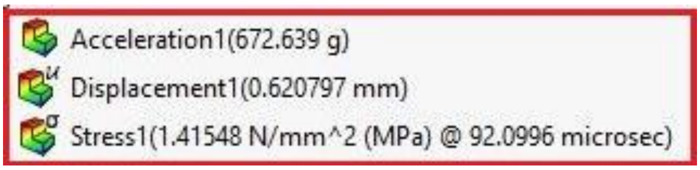

Fig -7: Sensor data on Top face of EPS Foam

3.2 Analysis of Honeycomb Matrix

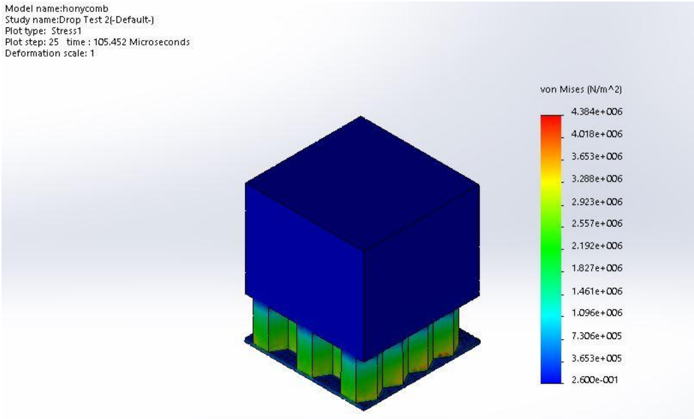

Fig -8: Von-Mises stress distribution in Honeycomb structure

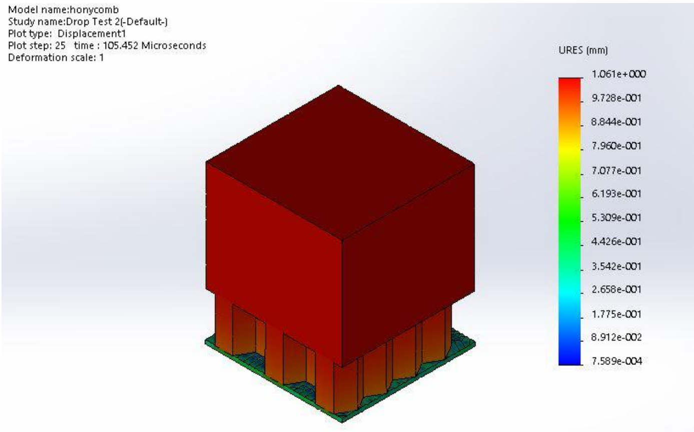

Fig -9: Displacement field in Honeycomb structure

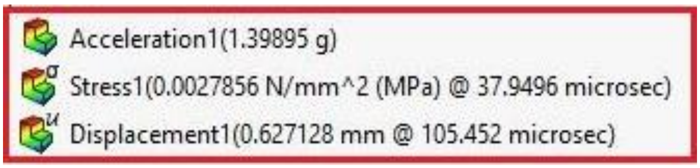

Fig -10: Sensor data on Top face of Honeycomb Structure

3.3 Analysis of Miura-Ori Matrix

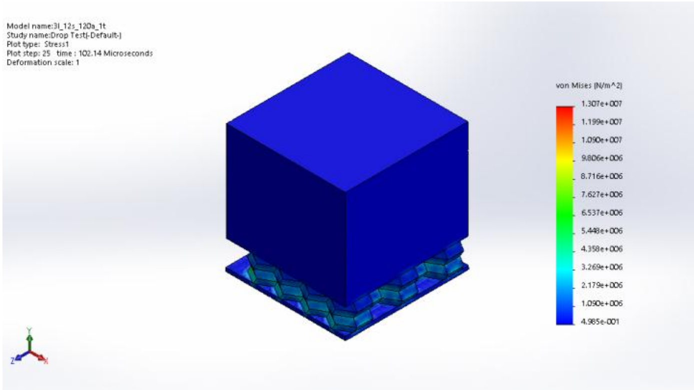

Fig -11: Von-Mises stress distribution in Miura-Ori structure

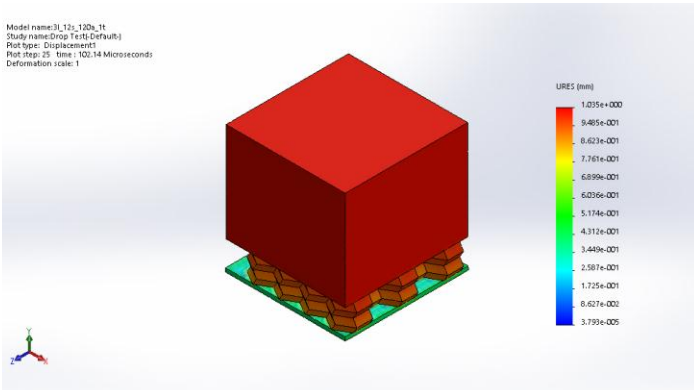

Fig -12: Displacement field in Miura-Ori structure

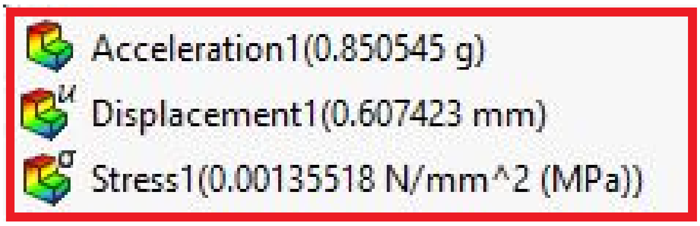

Fig -13: Sensor data on Top face of Miura-Ori structure

4. RESULTS

The result of the drop test simulation are obtained and is directly proportional to the type of meshing. The Von-Mises stress, displacement and acceleration of the headform is compared in all the three structure. Also these parameter are observed on top face of the structures. The significance of the acceleration data is that it corresponds directly to the impact force on the headform. Lower values of acceleration show that the forces on the headform are less, and hence implies that the majority of the impact force is absorbed by the structure itself. The study results are tabulated below.

Table- 2: Result of Drop Test Simulation On Top Face

STRUCTURE	**ACCLERATION (G)**	**STRESS (MPa)**	**DISPLACEMENT (MM)**
EPS FOAM	672.6390	1.4155	0.6207
Honeycomb	1.3989	0.0028	0.6272
Miura- Ori	0.8505	0.0013	0.6074

5. CONCLUSION

The paper describes the comparison of various impact absorption structures to replace the EPS foam in safety helmets. The results obtained after simulation shows that the designed Miura-Ori structure provides better impact absorption than EPS foam and Honeycomb structure. The study successfully shows that the acceleration on the headform is minimum in the Miura-Ori structure and hence the transmitted force in Miura-Ori structure is less as compared to other structure which results to increase in safety.

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REFERENCES

[1] Nicholas Turner, Bill Goodwine and Mihir Sen, "A review of origami applications in mechanical engineering," Proc IMechE Part C: J Mechanical Engineering Science 2016, Vol. 230(14) 2345–2362.

[2] Anup Pydah, R.C. Ba, " Crush dynamics and transient deformations of elastic-plastic Miura-ori core sandwich plates," Thin-Walled Structures Volume 115,Jume 2017,Pages 311-322.

[3] Mark Schenk and Simon D. Guest, "Geometry of Miura-Folded Metamaterials," PNAS February 26, 2013 110 (9) 3276-3281.

[4] Farshad Tavallalinia, "Effect of Helmet in Preventing Human Head and Brain Trauma in Traffic Accidents," unpublished.