Impact Assessment on Aerospace Structures

Augusta Bhardwaj (200103025)

Harsh Yadav (200103049)

BTP Supervisor: **Dr Niranjan Sahoo**

Department of Mechanical Engineering
Indian Institute of Technology Guwahati

ME 398 BTP Presentation

27 April 2024, IIT Guwahati, Guwahati, India

Plan of Presentation

- Introduction
  - Project Overview
  - Background
- Motivation and Objective of the Work
- Methodology (Metal Foams)
- Process of Making Metal Foams
- Compression test study and Effect of Graphene
- Theoretical Analysis
- Methodology (Numerical & Simulation Modelling using ABAQUS)
- Results
- Conclusions

Introduction

Project Overview

- Our project is focused on the goal of coming up with an energy-absorbing material that can be used to protect objects from shock impacts where a sudden input of energy results in accidents and casualties, through the study and research of lightweight energy-absorbing materials.

Background

- As we started to dwell deep into the understanding of Lightweight energy absorbing materials, Last semester we learnt about the Aluminium Alloy foam as an excellent choice for light weight energy absorption.
- We studied the properties of aluminium foam for addition of graphene and its effect on the properties.
- During an impact, metallic foams deform, increasing the total time of energy dispersion and thus reducing the resulting forces on the body.
- We learnt about the simulation methods and comparison on ABAQUS.

Motivation and Objective of the Work

- Based on the literature review, metal foams and aluminum foam sandwich have shown a multitude of progress in energy absorption. Therefore in order to study about them we needed to prepare computer simulations and study the conditions and property of metal and foams on impact.
- All of the studies were devoted to learn and understand the structure ,properties and manufacturing procedures etc of the metal foam and to make a 3D model on ABAQUS.

This motivates the need to study energy-absorbing material to reduce shock impact

Objective of the Work

(a) To learn ABAQUS software and make 2D and 3D models of an Aluminium Foam Sandwich and other materials to study and compare the results with that of experimental results.

(b) To make a 3D model for Aluminum foam in ABAQUS and perform Theoretical Analysis.

Methodology (Metal Foams)

- Importance of Metal Foams
  - During an impact, metallic foams deform, increasing the total time of energy dispersion and thus reducing the resulting forces on the body.
  - They offer the potential for lightweight structures, energy absorption, and for thermal management; and some of them, at least, are cheap.
  - They are very light (low density) compared to their respective metals and the cost of production of metallic foam is also relatively low.

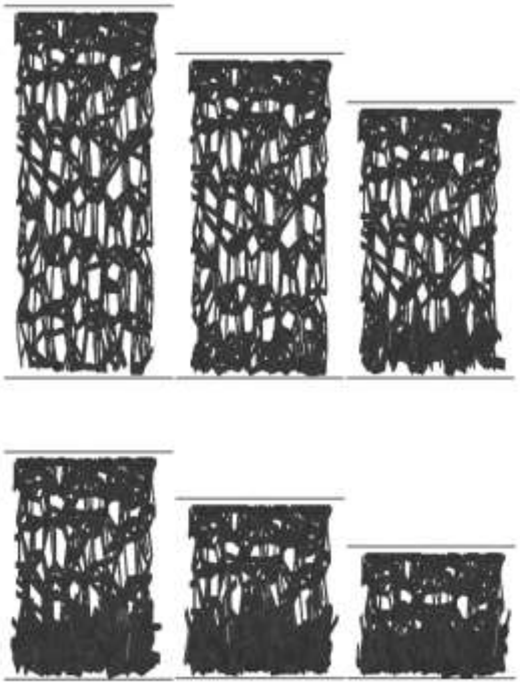
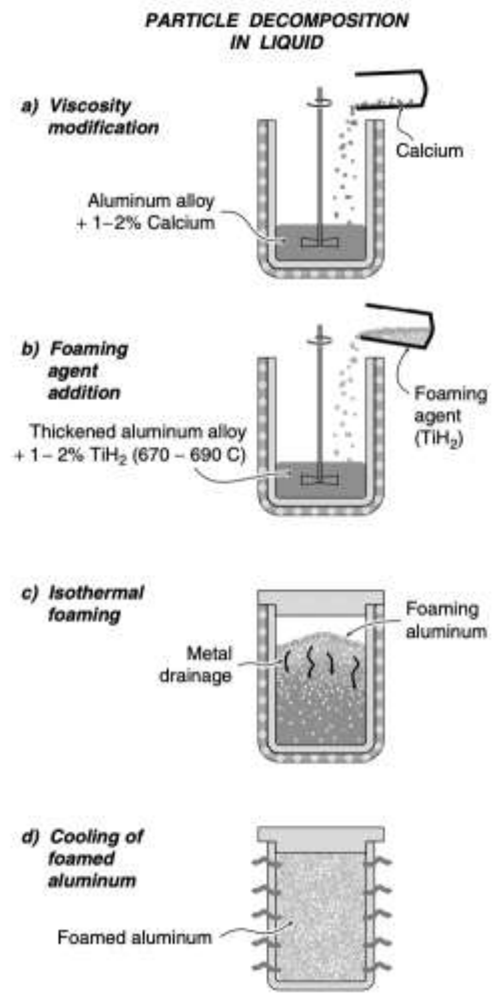


Image Source :
Metalfoam/Wikimedia Commons

Process of Making Metal Foams

- Making of metallic foams
  - The process begins by melting aluminium and stabilizing the melt temperature between 670°C and 690°C. Its viscosity is then raised by adding 1–2% calcium, rapidly oxidising and forming finely dispersed CaO and CaAl2O4 particles.
  - As soon as these are dispersed in the melt, the stirring system is withdrawn, and foam is allowed to form above the melt under a controlled environment by adjusting the pressure, temperature and time of foaming
  - Finally the mix is cooled in a controlled way which for the metal foam structure.

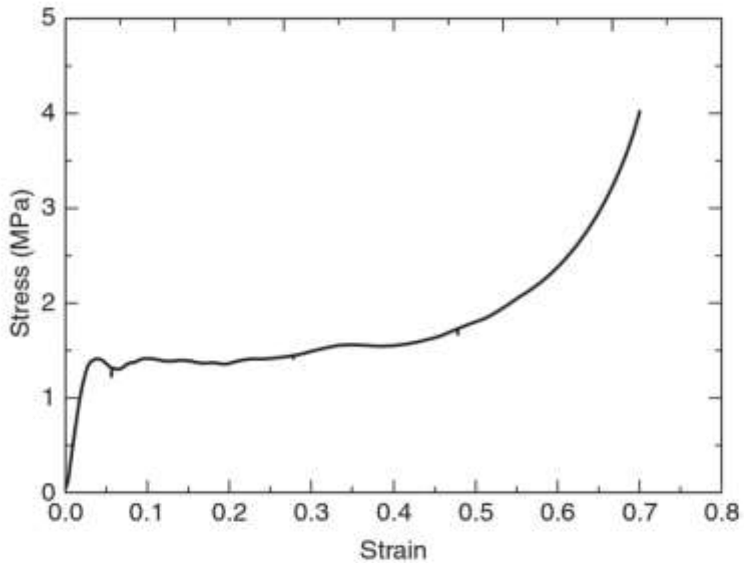


The process steps used in the manufacture of aluminium foams by gas-releasing particle decomposition in the melt (Alporas process)

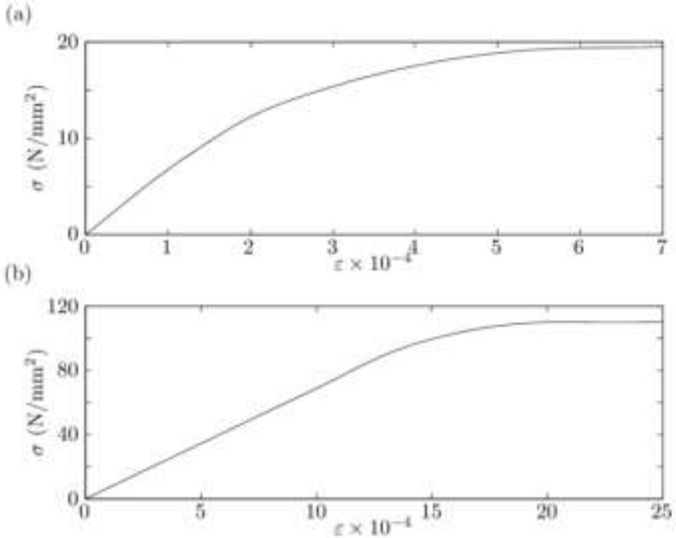
Compression test study and Effect of Graphene

Source Article:
N A Endut et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 290 012084
Experimental Evaluation of Interactive Buckle Localization in Compression Sandwich Panels
JO - Journal of Sandwich Structures & Materials.

- Uniaxial compression test
  - A typical uniaxial compression stress-strain curve for an aluminium foam is shown. The slope of the initial loading portion of the curve is lower than that of the unloading curve. Surface strain measurements indicate that there is localized plasticity in the specimen at stresses well below the compressive strength of the foam, reducing the slope of the loading curve.
- Stress-Strain Curve of Aluminium Foam and Aluminium rod



Stress-strain curves for Aluminium Foam Sandwich.



Stress-strain curves for (a) pure aluminium and (b) aluminium alloy

Compression test study and Effect of Graphene

- Composition of aluminium alloy foam and Graphene reinforcement
  - We studied Aluminium LM13 alloy which has a constant 3% wt. Boron Carbide (B4C) is prepared through stir casting.
  - Furthermore, the foam consists of 0.5%wt graphene reinforcement and is prepared through the “ Gas release in the melt ” technique, using CaCO3 as the foaming agent.
  - The varying composition of graphene has been studied, which gives varying results on the size of the plateau region during an impact, which was maximum for 0.62 % wt. in contrast, showing minimum results for 0.4 % wt. of graphene. However, a graphene-added hybrid foam consistently exhibits better energy absorption and plateau stress than one without graphene.
- Aluminium Foam Sandwich
  - One of the superior metal foams used by previous researchers in automotive applications is the aluminium foam sandwich due to its unique properties, such as low density and high energy absorption characteristics.

Compression test study and Effect of Graphene

- Aluminium foam sandwich panels are good energy absorbers and lightweight, providing a wide range of applications in automotive industries.
- The sandwich panel structures with aluminium foam core and metal surfaces have lightweight with high performance in dispersing energy. This has led to their widespread use in the absorption of energy. The cell structure of the foam core is subjected to plastic deformation in the constant tension level that absorbs a lot of kinetic energy before the destruction of the structure.

- Effect of Graphene reinforcement

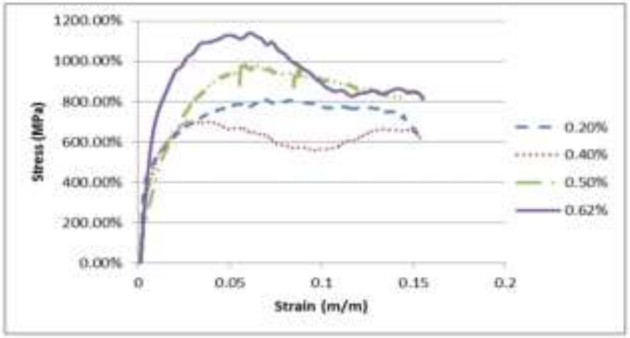


Figure 3.2 High strain rate ($1000\ s^{-1}$) compressive stress-strain response for different graphene composition

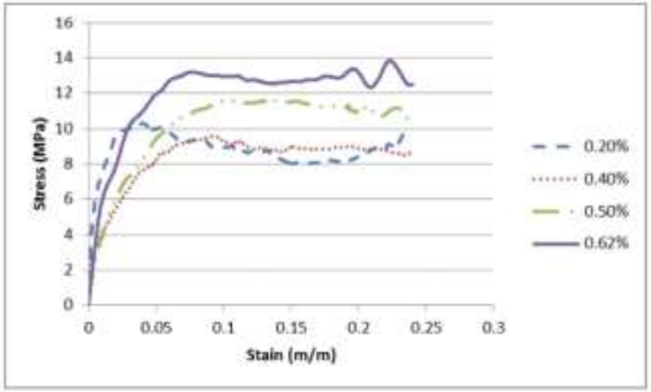


Figure 3.3 High strain rate ($1400\ s^{-1}$) compressive stress-strain response for different graphene composition

Source Article: thesis by amitananad sinha at university of missouri coloumbia

Theoretical Analysis

- The analytical solution for impact on composite material target made of laminated woven fibers based on matrix is presented. Therefore, the analysis of material properties for unidirectional laminates is used to develop material properties of woven fiber composite. Types of observed energies due to impact are developed and evaluated

- ## Unidirectional lamina

for the effective properties $E_{11},\ \nu_{12}$ and G_{12} and closed bounds for properties E_{22} and ν_{21} and for the assumptions of transfers of isotropic fibers and isotropic matrix, a

$$E_{11} = E_m V_m + E_f V_f$$
$$\nu_{12} = \nu_m V_m + \nu_f V_f$$
$$G_{12} = G_m \left(\frac{V_f}{1/(G_f - G_m) + V_m/2G_m} \right)$$

$$E_{11} = \frac{E_m E_f}{E_m V_f + E_f V_m}$$

$$\nu_{21} = \frac{E_{11}}{E_{22}} \nu_{12}$$

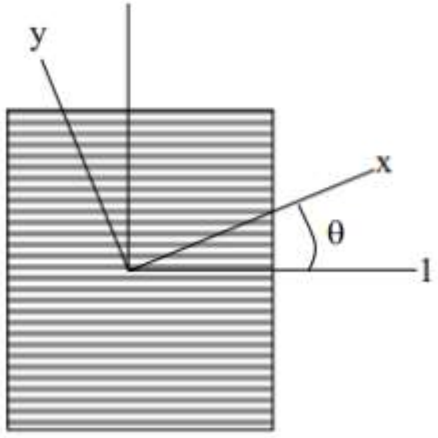


fig 2.1 Composite fiber lamina

Theoretical Analysis

For angled ply :-

$$E_{xx} = \left[\frac{m^4}{E_{11}} + \left(\frac{1}{G_{12}} - \frac{2v_{12}}{E_{11}}\right) m^2 n^2 + \frac{n^4}{E_{22}}\right]^{-1}$$

$$G_{xy} = \left[\frac{1}{G_{12}} + 4\left(\frac{1 + 2v_{12}}{E_{11}} + \frac{1}{E_{22}} - \frac{1}{G_{12}}\right) m^2 n^2\right]^{-1}$$

$$E_{yy} = \left[\frac{n^4}{E_{11}} + \left(\frac{1}{G_{12}} - \frac{2v_{12}}{E_{11}}\right) m^2 n^2 + \frac{m^4}{E_{22}}\right]^{-1}$$

$$v_{xy} = E_{xx}\left[\frac{v_{12}}{E_{11}} - \left(\frac{1 + 2v_{12}}{E_{11}} + \frac{1}{E_{22}} - \frac{1}{G_{12}}\right) m^2 n^2\right]$$

Random oriented discontinuous fibre composite

For the same fiber aspect ratio and same volume fraction of that to determine the prosperities of unidirectional fiber composite the isotropic properties of the random oriented discontinuous fiber composite are given by

$$G = \{E_{11} + 2E_{22}\}/8$$

$$E = \{3E_{11} + 5E_{22}\}/8$$

For woven fibres of finite-end satin, the properties will be decreased due to

fibres bent

$$(\boldsymbol{E}_{11})_{\boldsymbol{w}} = (\boldsymbol{E}_{22})_{\boldsymbol{w}} = \boldsymbol{W}_{\boldsymbol{E}}(\boldsymbol{E}_{11})_{\infty} = \boldsymbol{W}_{\boldsymbol{E}} \frac{\left\{\left(1 + \frac{\boldsymbol{v}_{21}}{\boldsymbol{v}_{12}}\right)^2 - 4\boldsymbol{v}_{21}^2\right\}}{2(1 - \boldsymbol{v}_{12}\boldsymbol{v}_{12})\left(1 + \frac{\boldsymbol{v}_{21}}{\boldsymbol{v}_{12}}\right)} \boldsymbol{E}_{11}$$

Theoretical Analysis

Impact analysis

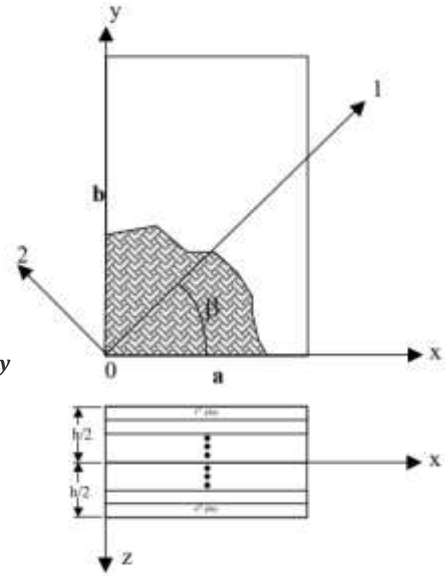
The research of impact of woven hybrid composites has been experimental and Numerical. In order to understand the mechanisms in the woven hybrid composite under low, high and ballistic velocities for impact, and the energy transfer between the impactor and the composite, analytical models are needed.

A laminated composite plate of length a, breadth b and thickness h with n arbitrarily oriented layers is considered. The plate axes and the layer details are illustrated in Fig.

$$\mathbf{u}(\mathbf{x},\mathbf{y},\mathbf{z}) = \mathbf{u}^0(\mathbf{x},\mathbf{y}) + \mathbf{z}\,\boldsymbol{\theta}\mathbf{x}(\mathbf{x},\mathbf{y})$$

$$\mathbf{v}(\mathbf{x},\mathbf{y},\mathbf{z}) = \mathbf{v}^0(\mathbf{x},\mathbf{y}) + \mathbf{z}\boldsymbol{\theta}\mathbf{y}(\mathbf{x},\mathbf{y})$$

$$\mathbf{w}(\mathbf{x},\mathbf{y},\mathbf{z}) = \mathbf{w}^0(\mathbf{x},\mathbf{y})$$



$$\boldsymbol{\epsilon}_\mathbf{x} = \frac{\partial \mathbf{u}}{\partial \mathbf{x}} = \boldsymbol{\epsilon}_\mathbf{x}^0 + \mathbf{z}\mathbf{k}_\mathbf{x} \qquad \epsilon_y = \frac{\partial u}{\partial x} = \epsilon_y^0 + zk_y \qquad \gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} = \gamma_{xy}^0 + zk_{xy}$$

$$\gamma_{xy}^0 = \frac{\partial w}{\partial x} + \theta_x \qquad \gamma_{yz}^0 = \frac{\partial \omega}{\partial y} + \theta_y$$

$$\{\boldsymbol{\sigma}\} = \left[\overline{Q}_{i_j}\right]_k \{\boldsymbol{\varepsilon}\}$$

Theoretical Analysis

Energy Balance

Based on the conservation of the total energy, the part of the kinetic energy of the projectile is absorbed by the plate, and assumed to be classified into four types which are: - 1- The strain energy due to dynamics of plate's theory (Contact energy) Uc . 2- Strain energy in the large deflection penetration zone ULd . 3- Delamination strain energy Udel. 4- Friction energy UF. The energy balance according to this classification for the impact becomes

$$\frac{1}{2}M_p v_{p_i}^2 = U_C + U_{LD} + U_{deL} + Uf + 1/2\, MV\text{^}2$$

Strain energy due to deformation of plate The equation of motion for the laminated composite plate subjected to dynamic load (impact) is

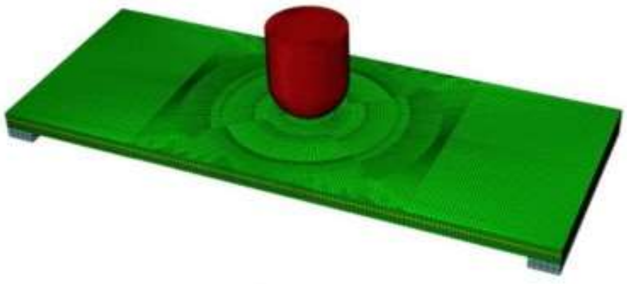
$$D_{11}\frac{\partial^4 w}{\partial x^4} + 2(D_{12} + D_{66})\frac{\partial^4 w}{\partial x^2 \partial y^2} + D_{22}\frac{\partial^4 w}{\partial y^4} + \rho h\frac{\partial^2 w}{\partial t^2} = q(x, y, t)$$

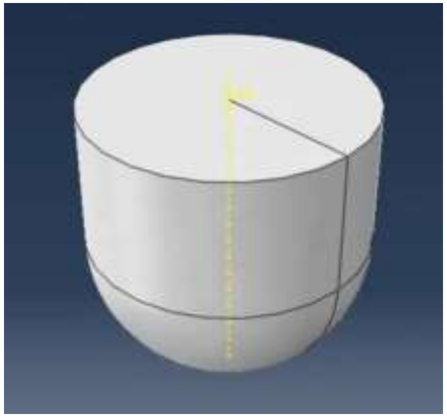
w(x,y) is the deflection along the z direction. q(x,y,t) is the intensity of transverse distributed load per unit area acting on the thin plate.D11, D16, D12, D66, D26, D22 are the flexural rigidity coefficients of the laminated plate. For especially orthotropic laminates (D16 = D26 =0), the governing differential equation becomes.

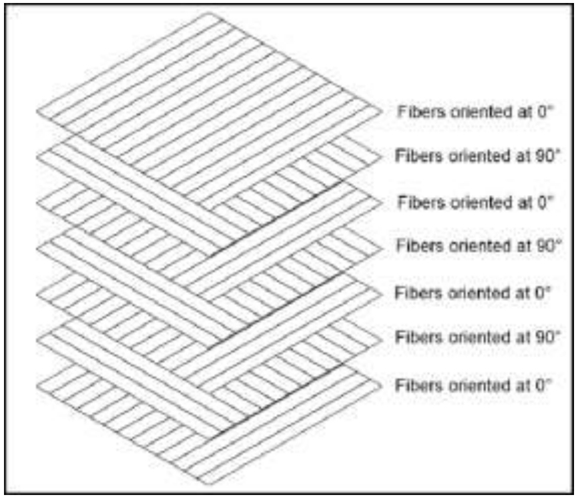
$$D_{11}\frac{\partial^4 w}{\partial x^4} + 2(D_{12} + D_{66})\frac{\partial^4 w}{\partial x^2 \partial y^2} + D_{22}\frac{\partial^4 w}{\partial y^4} + \rho h\frac{\partial^2 w}{\partial t^2} = q(x, y, t)$$

Methodology (MODELING USING ABAQUS)

- Impact modelling using ABAQUS CAE
  - This model is an example of a spherical shaped steel projectile being fired at a laminated composite carbon/epoxy plate.
  - The laminated plates are arranged in [0/90]s fibre orientation(cross ply orientation).
  - The model contains rigid spherical projectile of 14 mm diameter on target of deformable laminated plates of dimension 150mm x100mm x 2mm.

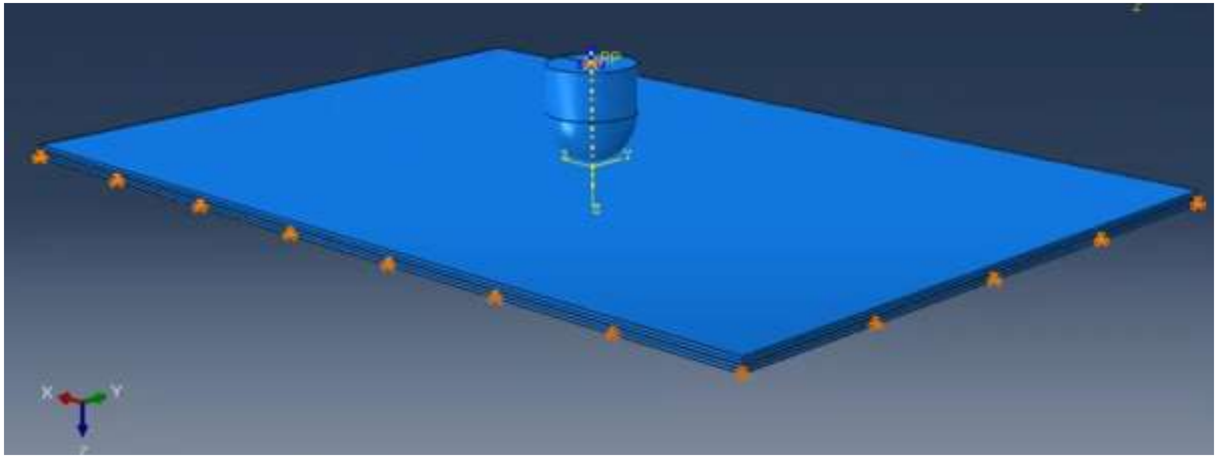






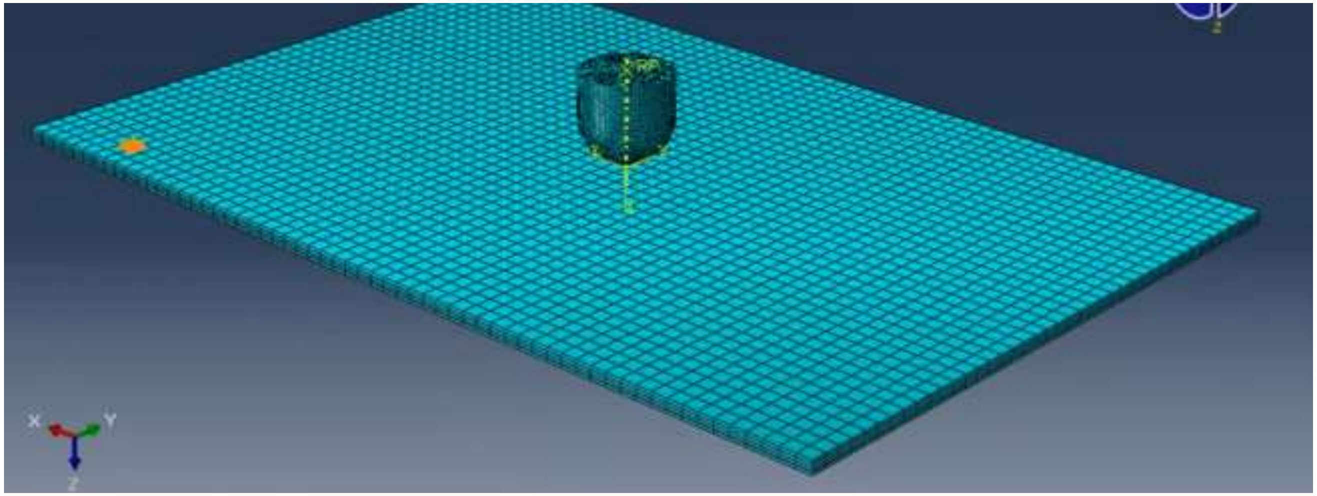
Methodology

- Properties and assembly type
  - The laminated sheets are elastic and of density 1600 kg/mm3 with the mechanical damage on them being the Hashine damage(i.e., a progressive damage model).
  - The impactor is a steel made isotropic mass of 3.12 kgs
  - Elastic Properties:- E1= 130 GPa , E2=E3= 7.7GPa; v12=v13=0.3; G12=G13=4.8GPa; G23=3.8GPa.
  - Strength Properties:- Xt=2080MPa , Xc=1250MPa; Yt=62MPa , Yc=240MPa; S12=S13=110MPa , S23=80MPa.
  - Fracture Energy:- G1t=133N/m, G1c=10N/m; G2t=0.6 N/m; G2c=2.1N/m.



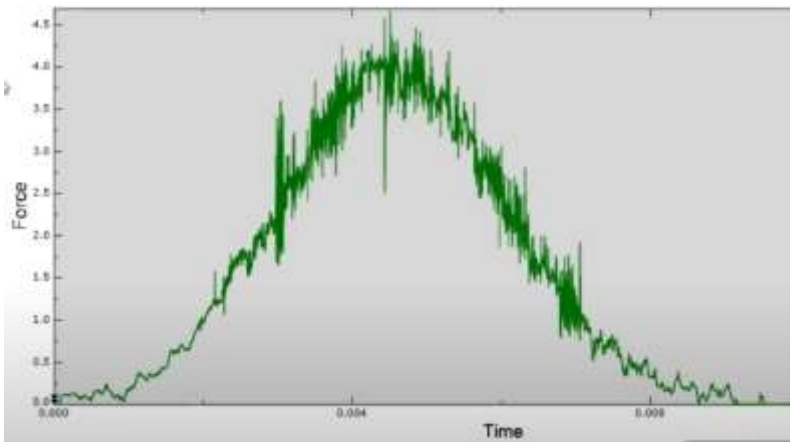
Methodology

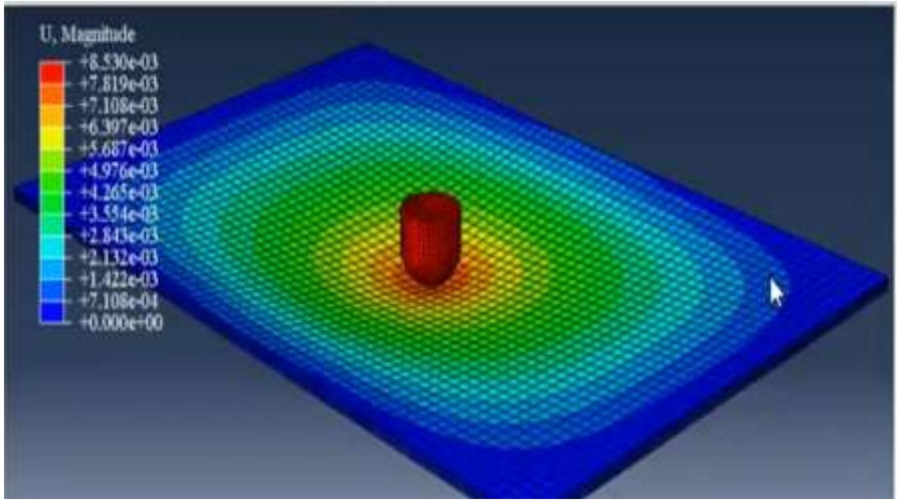
- Impact modelling
  - As our modelling is based on high speed impacts we use Dynamic Explicit analysis with general procedure on ABAQUS.
  - For interaction module ,use the default hard normal behaviour and tangential behaviour with 0.3 penalty friction.
  - The laminated plates are pinned i.e. fixed at the ends while the projectile moves in z-direction only with 2.5m/s velocity.
  - In global seed we chose hex shaped elements and a mesh size of 2.5mm and explicit continuum shell for both , the sheets and the impactor.

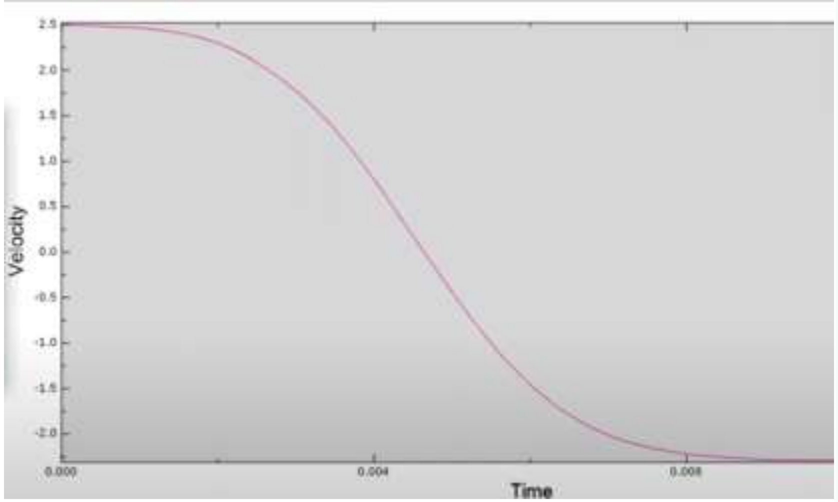


Results and Post-Processing

- The force peaks during the impact as seen in the graph.
- Force is maximum at the point of contact and disperse evenly on the surface.
- Velocity of the projectile decays with time after impact.







Conclusions

- We learnt the following things throughout research till now:-
  - Why do we use metal foams instead of conventional metal sheets
  - What are aluminium foam sandwich and their compositional and structural analysis?
  - Effect of graphene reinforcement on energy absorption.
  - The manufacturing method of aluminium foams
  - Different structures of aluminium foams
  - Study of compressive stress-strain curve compressive behaviour of aluminium foam upon impact.
  - Theoretical Analysis and Equation involved.
  - Effects of impact on a Carbon fibre composite through ABAQUS simulations.

-

Thank You !