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Numerical Investigation of Low Velocity Impact on Polystyrene Foam Core Based Sandwich Composites

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ABSTRACT

A numerical study on a low-velocity impact on polystyrene foam core based sandwich structure was conducted. Sandwich composite with polystyrene foam core and mild steel sheet as skin was considered for modelling in Abaqus CAE 6.14 platform. Low velocity impact simulation was performed on the sandwich structure by varying impactor mass for constant impact velocity and by varying impact velocity for constant impactor mass. The primary focus was to investigate the variation of contact force, contact time, displacement and principal strain with respect to both variables and to find out the impact energy threshold for damage initiation. The model was validated by using existing literature for contact force history. Theoretical results were found to be well predicted by simulation. The variation of impact velocity for constant impactor mass does not have any effect on contact time. No damage in the sandwich was found up to impact energy of 8J.

Keywords: Low velocity Impact, Composite, Sandwich, Polystyrene Foam, Simulation

1. Introduction

Sandwich structure is a special type of composite material tailored with two thin but high strength facings and a core in between them which is a relatively soft material. Even though the core material is low in strength, but its higher thickness furnishes the material with high bending stiffness with low density [1, 2]. The purpose of sandwich structure is to achieve a stiff as well as light component. Many alternative forms of sandwich construction may be obtained by combining different facing and core materials. The facings consist of steel, aluminum, wood, fiber-reinforced plastic or even concrete and the core material may be made of rubber, balsa wood, cork, rigid foam material (polyurethane, polystyrene, phenolic foam), solid plastic material (polyethylene), mineral wool slabs or from honeycombs of metal or even paper [3]. Sandwich structures usually find their applications in fabricating aircraft, ships, automotive vehicles, building walls and ceilings and many other lightweight constructions. Many noticeable characteristics of sandwich composites such as light weight, high strength, high stiffness, good fatigue resistance, good corrosion resistance and manufacturing complex geometries with fewer components lead to increasing demand day by day in wide range of fields [4].

Polystyrene is a thermoplastic material which can be re-formed by heating. It is a good thermal insulating material but it is rather less significant in terms of application to sandwich panels as it possess low self-bonding properties with the faces. Hence, Polystyrene is attached to the facing material with adhesives. It is usually used where small quantities of relatively simple design are required [3] because of the inexpensive production equipment. Foamed polystyrene which is a low cost, easily available, lightweight, and good energy absorption and thermal insulator material may be a potential candidate core material for manufacturing sandwich composites.

Sheet metal is manufactured by industrial process such as forging, extrusion etc. into thin, flat pieces. It is one of the most common structures utilized in metalworking and can be cut and bent into an assortment of shapes. Thickness can differ significantly, too thin sheets are considered as foil or leaf, and pieces thicker than 6 mm are considered as plate. Mild steel contains a very small percentage of carbon about 0.05–0.25% carbon. It is strong and tough but not readily tempered and also known as plain-carbon steel and low-carbon steel. This form of steel is most recognized and used as it is relatively cheap while providing material properties that are suitable for many applications. Low carbon in mild steel allows making it malleable and ductile. Mild steel has a relatively low tensile strength, it is easy to form and its surface hardness can be increased through carburizing [5]. Mild steel sheet may be a good facing material for the construction of sandwich structure because of its low cost, high stiffness and availability.

During manufacturing or in service, sandwich structures are often subjected to low velocity impact resulting from tool drop and unintentional striking. In case of sandwich structures, numerous studies have shown that a low-energy-impact caused by dropped tools, runway debris, hailstones etc., may result in a small indentation that is barely detectable or undetectable by visual inspection. Though the indentation is undetectable, the impact on the object may cause internal damage in the form of face sheet delamination, fiber fracture, matrix cracking, and core crushing. The presence of such undetected damage in load-carrying components may lead to severe structural failure at a fraction of design load through several mechanisms including unstable indentation growth, face-sheet kink band formation and propagation, delamination buckling, and fiber failure.

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Therefore, the behavior of sandwich structures under low-velocity impact has been receiving increasing attention. To investigate the impact damage resistance of composite sandwich structures many experimental studies have also been proposed [6-8].

Finite element analysis (FEA) method has been used for predicting absorbed energy, failure strain, contact force, displacement, stress, deformation etc. during impact loading. The most important advantage of FEA is that it is possible to model any object having complex geometry and several number of variables can be studied at low cost and within short period of time by reducing number of experiments involving money and time. There are many FEA studies on foams in literature and new constitutive models are being implemented into finite element codes.

In this study, a sandwich structure consisting of polystyrene foam as core material and mild steel sheet as facing is considered. A numerical model is developed in Abaqus CAE 6.14 to study the effects of low velocity impact on the sandwich structure. The concentration was on impact force limit, displacement, contact time, energy absorption, and principal strain for various impact velocities at constant impactor mass and for various impactor masses at a constant impact velocity.

2. Numerical Modeling

The dimensions of the core and skin were 150 mm × 150 mm × 15 mm and 150 mm × 150 mm × 0.8 mm respectively as shown in Fig.1. The impactor having 10 mm diameter and 19 mm height was assigned with rigid body behaviour to it. The experimental stress-strain curve and other properties for polystyrene foam were taken from Ref. [2] as mentioned in Table 1.

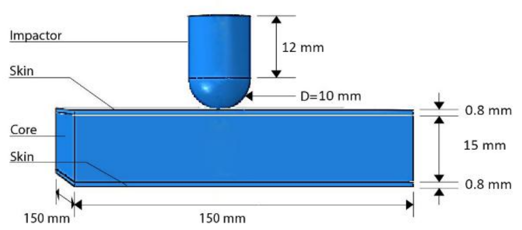


Fig.1 Setup for analysis

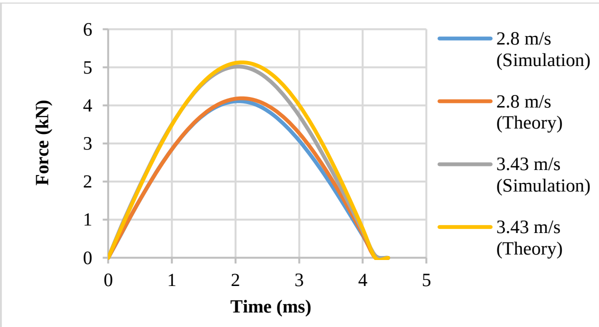
For MS sheet, the properties were assigned according to AISI standards as mentioned in Table 1 [4]. After assembly the impactor was kept offset from surface 0.02 mm. The contact between the face and core was provided by merging the assembled part since the elastic behaviour was studied and the contact between the sandwich and impactor was simulated using GENERAL CONTACT ALGORITM. Linear brick elements were used with reduced integration and hourglass control options (C3D8R). The sides of the sandwich composite were fully constrained. The contact friction coefficient between the face and the impactor was set as μ = 0.3 as the friction coefficient of polystyrene and mild steel is ranged from 0.3-0.35. The velocity of the impactor was set only in z-direction with predefined field velocity. The appropriate mesh size is selected based on mesh dependency test and computational time.

Table 1 Material properties of foam core sandwich component

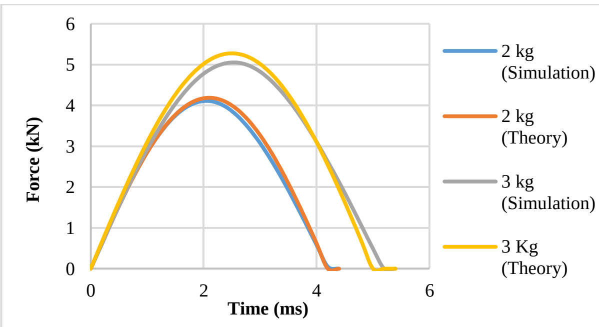
Material	Young's Modulus (GPa)	Poisson's Ratio	Density (kg/m^3)
Mild Steel	205	0.29	7780
Polystyrene	8.1E-3	0.1	30

3. Results and Discussion

For constant impactor height i.e. impact velocity analysis, the mass of the impactor was varied from 1 kg to 3 kg with an increment of 0.5 kg and for constant mass analysis, the height of the impactor was varied from 200 mm to 600 mm with an increment of 100 mm. Constant velocity and constant mass impact were simulated by varying the impactor mass (1.0 kg, 1.5 kg, 2.0 kg, 2.5 kg, and 3.0 kg) at a constant impactor velocity of 2.8 m/s and by varying the impact velocity (1.98 m/s, 2.43 m/s, 2.80 m/s, 3.13 m/s, and 3.43 m/s) for a constant mass of 2.0 kg respectively. The effect of these two types of impact



(a)



(b)

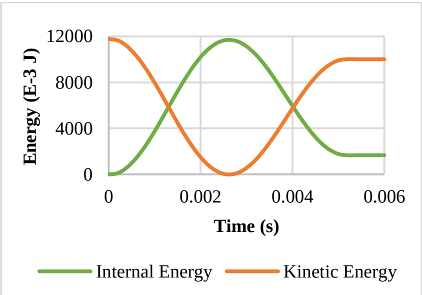
Fig.2 Force vs time comparison between simulation and theoretical results for (a) various impactor velocities for a constant impactor mass and (b) various impactor masses at a constant velocity.

phenomena on energy, contact force, displacement and principal strain were investigated.

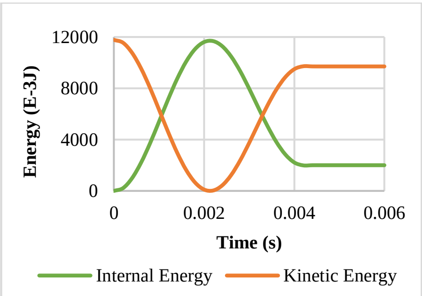
The verification of this numerical analysis was performed using the analytical model of force-time history. Choi [9] approximated the impact force history as –

$$F_l(t) = \frac{2\pi m_l v}{T_l} sin \frac{2\pi t}{T_l} \qquad \left(0 \le t \le {}^{T_l}/_2\right) \qquad (1)$$

Where, F_l, m_l, v, T_l, and t are linear impact force, mass of the impactor, impact velocity, twice of impact duration and contact time respectively. The comparison of force vs time curve between simulation and theoretical (Eq. (1)) results at different impact velocities for a constant mass and for various impactor masses at a constant impact velocity is given in Fig.2. Theoretical results appear to be closely predicted the simulation results although a slight variation between simulation and theoretical results are noticed.



(a)



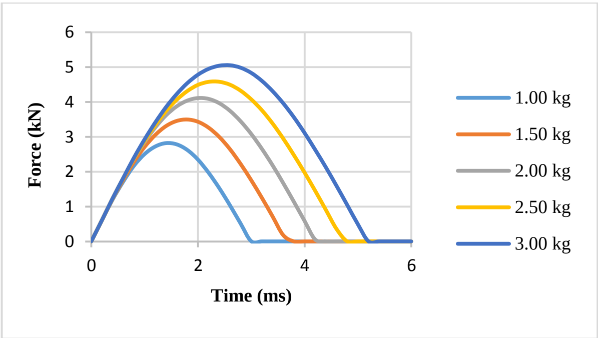
(b)

Fig.3 Typical energy vs time curves for (a) impact velocity of 2.8 m/s with impactor mass of 3 kg and (b) impactor mass of 2 kg with impact velocity of 3.43 m/s.

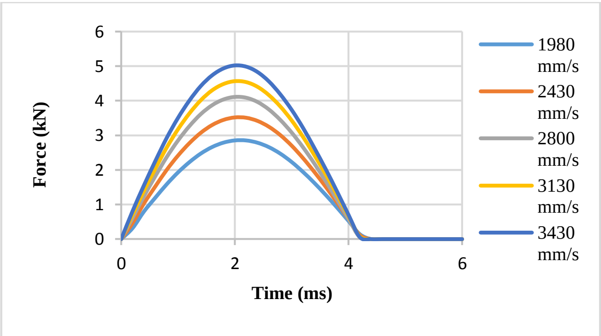
This is not unusual because the rebound velocity of the impactor is assumed to be equal to the impact velocity in the theory and losses are not considered due to friction. Nonetheless, the numerical results can be considered reliable for further analysis.

Fig.3 shows the typical variation of internal and kinetic energy with time for impact velocity of 2.8 m/s with impactor mass of 3 kg (see Fig.3(a)) and impactor mass of 2 kg with impact velocity of 3.43 m/s (see Fig.3(b)). The internal energy appear to increase non-linearly with increasing time until a maximum then decrease gradually to a constant value when the impactor is detached from sandwich and the kinetic energy of the impactor follows a completely opposite trend as expected in both type of impact phenomena. A small amount of energy absorption is noticed due to friction during impact in each case.

Contact force is plotted as a function of time in Fig.4 for various impactor masses with a constant impact velocity of 2.8 m/s (see Fig.4(a)) and for various impact velocities with a constant impactor mass of 2 kg (see Fig.4(b)). The contact force seems to increase linearly at the start of the impact then gradually until the pick and then the force decreases to zero but with an opposite trend at the end in both cases. The slope of force vs time curved for constant velocity impact appeared to be constant irrespective to the impactor mass change (see Fig.4(a)) while the slope increases with increasing impact velocity for a constant impactor mass (see Fig.4(b)).



(a)

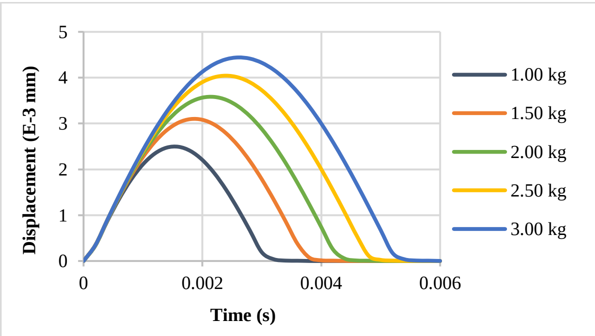


(b)

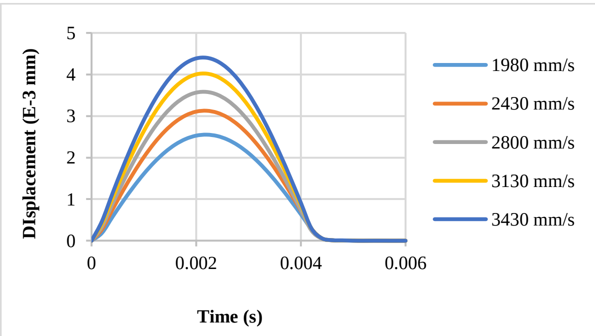
Fig.4 Contact force as a function of time for (a) various impactor masses with a constant impact velocity of 2.8 m/s and (b) various impact velocities with a constant impactor mass of 2 kg.

Displacement of the impact zone which comes in contact with the impactor from the beginning is found to be the maximum expectedly. The displacement vs time curve for different impactor mass with constant velocity and for different impactor velocity with constant mass is given in Fig.5. The curves show similar pattern as contact force vs time curves.

The force vs displacement curves for different analysis are shown in Fig.6. The slope of the force vs displacement curves during loading and unloading appeared to be same irrespective to the impactor mass change for constant impact velocity (see Fig.6(a)). On the other hand, the slope of the force vs displacement curve increases with increasing impact velocity for constant impactor mass (see Fig.6(b)). In both type of impact cases, the force increases/decreases linearly with displacement although a small deviation is noticed at the beginning of impact because of the contact establishment. The area bounded by the force vs displacement curves represents the amount of energy absorbed which increases with increasing impactor mass for constant impact velocity (see Fig.6(a)) and also increases with increasing impact velocity for constant impactor mass (see Fig.6(b)). It is also seen that energy absorption increases with increasing impactor mass for constant impact velocity and with increasing impact velocity for constant impactor mass.



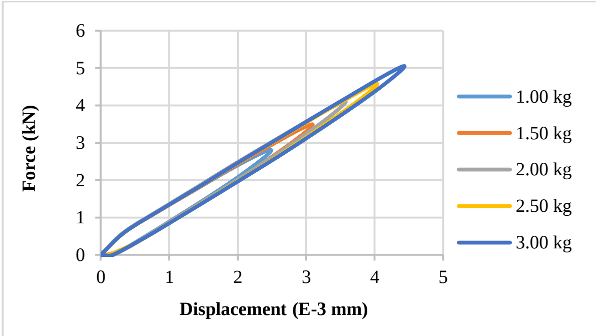
(a)



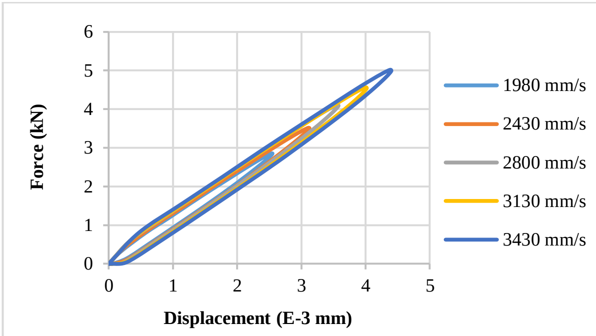
(b)

Fig.5 Displacement as a function of time for (a) various impactor masses with a constant impact velocity of 2.8 m/s and (b) various impact velocities with a constant impactor mass of 2 kg.

Maximum contact force is plotted as a function of total impact energy for constant velocity and constant mass impact in Fig.7. The maximum contact force increases non-linearly with increasing impact energy for both analyses and no significant difference in maximum contact force for constant impact energy is seen between these two analyses. Non-linear behavior of contact force is also reported by Akil and Cantwell [10] for foam core sandwich structure. Displacement vs impact energy curves show similar behavior as contact force vs impact energy curves as shown in Fig.8.



(a)



(b)

Fig.6 Force vs displacement curves for (a) various impactor masses with a constant impact velocity of 2.8 m/s and (b) various impact velocities with a constant impactor mass of 2 kg.

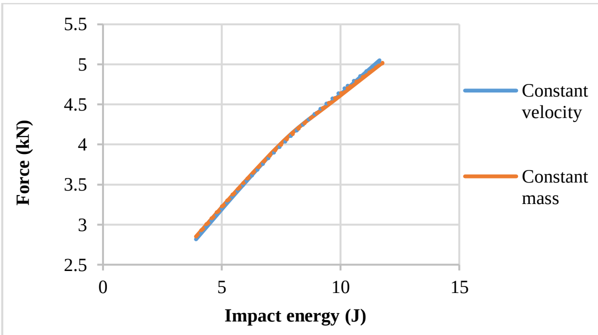


Fig.7 Maximum contact force as a function of impact energy for constant velocity and constant mass impact.

Contact time is plotted as a function of impact energy for both analyses in Fig.9. As the impact energy increases keeping the impact velocity constant, the contact time of the impactor increases linearly but when impact energy increases keeping the impactor mass constant, the contact time remains constant. This is because the duration and the shape of the contact force history are dependent on the mass ratio between impactor and sandwich but not on the velocity as stated in Ref. [11].

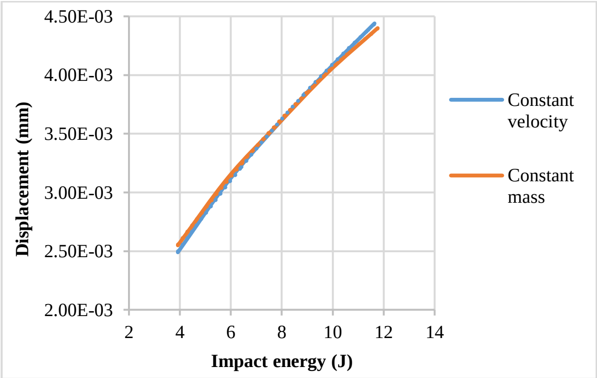


Fig.8 Maximum displacement as a function of impact energy for constant velocity and constant mass impact.

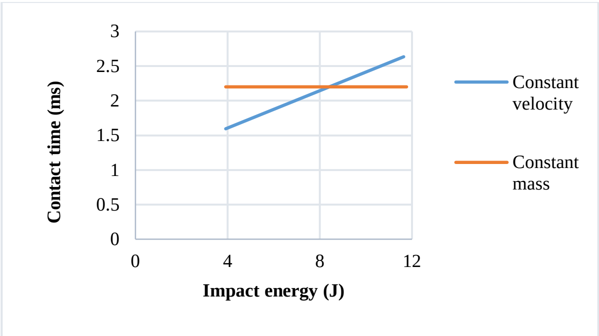


Fig.9 Contact time of impactor vs impact energy.

Maximum principle strain as a function of impact energy for both analyses is given in Fig.10. The maximum principle strain in the sandwich core increases linearly with increasing impact energy in both constant velocity and constant mass impacts and no significant difference

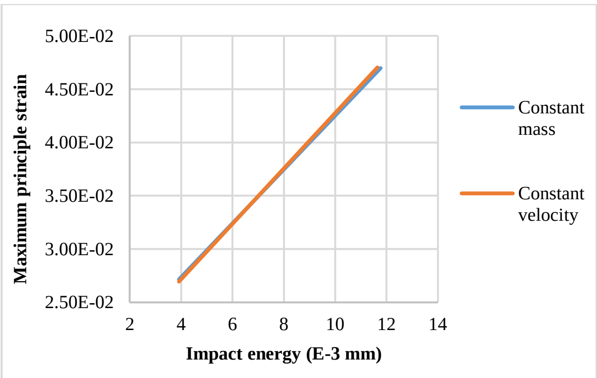


Fig.10 Maximum principle strain as a function of impact energy for constant velocity and constant mass impact.

is seen in maximum principle strain for constant impact energy between two analyses. Elastic limit of polystyrene foam is 4E-2 mm. From the curve (see Fig.10) it is seen that at impact energies higher than 8J the value of maximum principle strain is over the limit which indicates the failure of core when maximum principle strain failure is considered.

4. Conclusion

Low-velocity impact on sandwich panels with polystyrene foam core and mild steel face sheets were modelled numerically using Abaqus CAE 6.14 and the model was validated using existing theory in literature. The analysis was performed based on the energy of impact which was varied by changing impactor mass and impact velocity. The findings of the study are summarized below:

a) The contact force and displacement increases non-linearly with increasing impact energy with no significant variation between two analyses.
b) For constant mass analysis the contact time of the impactor with the sandwich remains constant but for constant velocity analysis the contact time increases linearly with increasing impact energy.
c) The maximum principle strain increases linearly with increasing impact energy irrespective to constant mass or constant velocity analysis.
d) The maximum impact energy limit for sandwich core damage initiation is found to be 8J independent of height of impactor and mass of impactor.

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