

## FEM ANALYSES OF LOW VELOCITY IMPACT BEHAVIOUR OF SANDWICH PANELS WITH EPS FOAM CORE

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### ABSTRACT

This study presents a numerical investigation on low velocity impact response of sandwich panels with EPS foam core. The face-sheets and foam core are made of aluminum 6061-T6 and expanded polystyrene foam (EPS). The effect of foam core density was investigated on the impact energy absorption of the panel. The dynamic response of the panels was predicted using the finite element analysis package ABAQUS/Explicit. The material and geometrical nonlinearities were considered and the foam material was modeled as a crushable foam material. The cohesive response of the adhesive interface was modeled using the cohesive zone model. The temporal variations of contact force, kinetic energy histories and central permanent deflections were compared for different foam core densities and impact energies. The peak contact force levels and central permanent deflections are increased with increasing the impact energies. As the foam core density is increased, the capability of energy absorbing is increased.

**Keywords:** *Impact, Sandwich Panel, Foam, Non-Linear Finite Element Analysis, Cohesive Zone Model*

### INTRODUCTION

Sandwich structures based on strong, stiff skins bonded to a low density core material are used widely in high-performance applications such as, aerospace industries, automotive, civil engineering and transportation industry due to their high in-plane and flexural stiffness, good acoustic and thermal insulation, high energy absorption capability, very good corrosion resistance [1-3]. Zhou et al. [4] studied the low velocity impact response of foam-based sandwich panels experimentally and numerically. They also investigated the effect of oblique loading on sandwich structures and determined the energy required to perforate the panels. Their test showed that the perforation resistance of the plain foams and their sandwich panels was strongly dependent on the properties of the foam core. At higher densities, the PVC foams and their associated sandwich structures offered a superior perforation resistance. Their FE analysis predicted the impact load-displacement responses and the perforation energies of both the plain foams and the sandwich panels. Hazizan and Cantwell [5] investigated the low velocity impact response of a range of foam-based sandwich structures. They used 11 foam materials and showed the indentation response of the sandwich structures using a simple indentation law. Different failure modes were resulted in low velocity impact test on the sandwich structures. Shear fracture was found to occur in the PVC/PUR systems based on brittle core materials. Buckling failures were observed in the uppermost composite skin in the intermediate modulus system. Xia and Wu [6] studied low velocity impact response of foam core sandwich composites in conjunction with various facing composed of glass, carbon, carbon/Kevlar hybrid and Kevlar fabric by using RTM process for three energy levels. Their results showed that the foam core with Kevlar facing were optimal for the peak load at load versus time plot. Smakosz and Tejchman [6] studied experimentally the strength, deformability and failure mode of composite structural-insulated panels in which the expanded polystyrene (EPS) foams were used. They tested specimens for bending, shear and compression, impact resistance, resistance to vertical and horizontal hanging loads and gradient thermal load. They showed that the composite structural-insulated panels had a better performance than those of the traditional structural insulated panels. Based on the experimental large-scale tests Composite Structural-Insulated Panels exhibited a common behavior, such as initially linear, then slightly non-linear and finally brittle at failure. Campilho et al. [8] implemented the cohesive zone model to the adhesive joints in order to predict the joint strength, and studied the effect of the cohesive law

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definition. They determined cohesive zone parameters using different cohesive zone laws as: triangular, exponential or trapezoidal. With this purpose, single-lap joints were bonded with a brittle and ductile adhesive and tested under tension. The brittle adhesive resulted in a smaller improvement as the joints failed at the overlap ends and the joints bonded with the ductile adhesive showed a major strength improvement. As the considering the different CZM shapes, these showed a significant effect on the results of the joints bonded. Wang et al. [9] investigated the low-velocity impact behavior of sandwich panels with foam core and plain weave carbon fabric laminated face-sheets, recorded and analyzed the transient responses of the samples. They considered impact variables as impactor diameter, impact energy, face-sheet thickness and foam core thickness for each of nine different foam core materials. The low-velocity impact caused some damage modes: permanent indentations having semi-spherical shapes under the impactor, matrix crushing due to compression, inter-ply and intra-ply matrix cracks, tow breaks, fiber fracture in foam-core sandwich panels with plain weave laminates. No delamination damage was observed in the impacted face-sheets. The impact response and damage state were independent of the foam core thickness. The three-dimensional finite element analyses with progressive damage model were in good agreement with the experimental tests.

Wang et al. [10] studied the impact response of sandwich panels with different core materials. Their sandwich panels were made of aluminum face-sheets with five different cores such as low density balsa wood, high density balsa wood, cork, polypropylene honeycomb and polystyrene foam. The impact properties of sandwich panels with the five different cores were compared in terms of contact force, energy absorption, depth of indentation, overall bending deflection. Their numerical model was carried out using the finite element software LS-Dyna. Their results showed that the core material was found to be very important in the target deformation, energy absorption, damage mechanism and penetration resistance of the sandwich panel. Ozturk and Anlas [11] studied the energy absorption of the polymeric foams (expanded polystyrene and polyethylene) under successive uniaxial compressive loading and unloading. They developed a new phenomenological constitutive model to calculate stress, strain, absorbed energy and energy efficiency in multiple uniaxial compressive loading and unloading. They found a good agreement between theoretical and experimental results. Their experimental measurements indicated that the stress-strain behavior in elastic loading and unloading regions changed considerably with the number of loadings. The new phenomenological constitutive model was offered as three separate equations for elastic loading region, non-elastic loading in plateau and densification regions and unloading region, respectively. Elnasri and Zhao [12] observed piercing force of sandwich panels with foam cores under impact loading by numerically and analytically. They used LS-DYNA to model sandwich panels and their model predicted piercing force vs. displacement curves in good agreement with experimental measurements. Their results showed that the foam core strength enhancement due to shock front propagation was responsible for this piercing force increased under impact loading. Their analytical model provided a prediction in good agreement with experimental and FE results in a large range of impact velocities. Gunes and Arslan [13] investigated the low velocity impact behaviour of sandwich structures with aluminum honeycomb core experimentally and numerically. They developed the numerical model of sandwich structures by using finite element method and it was in good agreement with experimental results in terms of contact forces and deformations. They also investigated the effect of the cell size and the height variation of aluminum honeycomb core by using this developed numerical model. The stiffness and stability of sandwich structure were increased with decreasing cell size of the honeycomb. However, the core height of honeycomb had a minor effect on the impact response of the sandwich plates. Feng and Aymerich [14] investigated the application of a finite element tool for simulating the structural and damage response of foam-based sandwich structures to low velocity impact. They used three dimensional damage models in the FE code ABAQUS/Explicit and interfacial cohesive laws for simulating damage modes occurring in the composite face-sheets, such as fibre fracture, matrix cracking and delaminations. They modeled foam core as crushable foam plasticity model. Their results were in good agreement between experimental data in terms of force histories, force-displacement curves and dissipated energy. Their model was also reproducing correctly the temporal sequence of the primary damage events, and good accuracy the planar extent of the damage area.

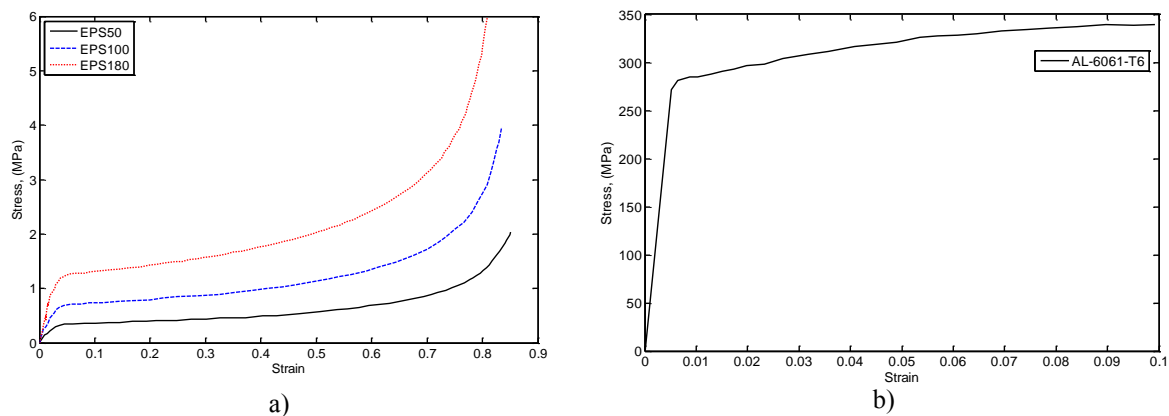
This paper proposes a numerical study of sandwich panels made with low density foam core and metal face-sheets under low velocity impact. The low velocity impact response of the sandwich panels is simulating three-dimensional non-linear finite element model to investigate the influence of the foam core density for different impact energy levels.

## Finite element model

The low velocity impact behavior of sandwich panels was studied using ABAQUS/Explicit (version 6.14) [15]. The impact behavior was investigated for different foam densities under three impact energy levels of 20, 40 and 80 J. Aluminum plates and expanded polystyrene were in dimension of 125x125 mm and were bonded using an epoxy based adhesive (Araldite 2015). The face-sheet thickness was taken as 1 mm, the core material was expanded polystyrene (EPS) foam in thickness of 10 mm and density of 50, 100 and 180 kg/m<sup>3</sup>. Adhesive thickness was taken as 0.25 mm for the impact analyses of the foam core sandwich panels. The face-sheets were modeled as an elasto-plastic material. The foam core was modeled as crushable foam material. The stress and strain curves of Aluminum (Al-6061 T6) and foam material (Expanded polystyrene) are shown in Figure 1 and the mechanical properties of sandwich panel components are listed in Table 1.

**Table 1.** The mechanical properties of sandwich panel components

Material	Al 6061	EPS		
		50	100	180
Density (kg/m <sup>3</sup> )	2700	50	100	180
Poisson's ratio	0.3	0	0	0
Young's modulus (GPa)	70	0.009	0.020	0.031
Yield stress (Mpa)	270	-	-	-

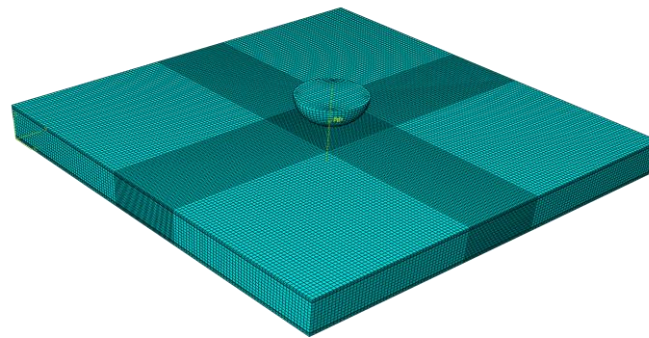


**Figure 1.** The stress and strain curves: a) foam core material (EPS) b) face-sheet material (Al-6061-T6)

The impactor was modeled as a rigid body behavior. The encastered boundary condition was applied to the sandwich panel. Both face-sheets and core foam were modeled using a three-dimensional solid finite element with three degrees of freedom at each node (C3D8R). The hourglass control was also used for the finite elements of core material as another option to avoid excessive element distortions and calculate numerical integrations accurately. The mechanical contact between the impactor, sandwich panel and impactor was simulated by the GENERAL CONTACT ALGORITHM in Abaqus/Explicit. The adhesive layer between the face-sheets and core foam is simulated by means of the cohesive zone approach. The interfacial adhesive failure was modeled through this cohesive zone layer between the face-sheets and core foam. The cohesive parameters of the epoxy adhesive were given in Table 2 [8] and a three-dimensional cohesive element (COH3D8) was used to model the cohesive response of the adhesive layer. The nominal traction stress vector  $t$ , with the components:  $t_n^0$ ,  $t_s^0$  and  $t_t^0$ , which represent the normal and the two shear tractions, respectively.  $G_n$  and  $G_s$  are the areas under the CZM laws in tension and shear. The cohesive thickness was taken as 0.25 mm for the adhesive layer. The finite element model of sandwich panel was shown in Figure 2.

**Table 2.** Cohesive parameters of adhesive Araldite 2015 used in CZM

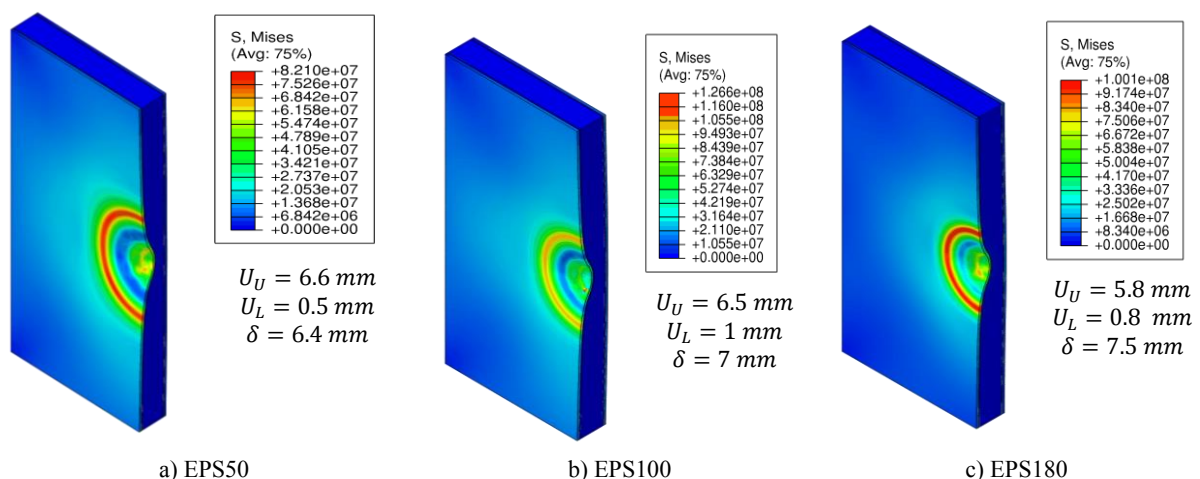
Property	Araldite 2015
E (GPa)	1.85
G (GPa)	0.56
$t_n^0$ (MPa)	21.63
$t_s^0$ (MPa)	17.9
$G_n^0$ (N/mm)	0.43
$G_s^0$ (N/mm)	4.70



**Figure 2.** Finite element model

## RESULTS AND DISCUSSION

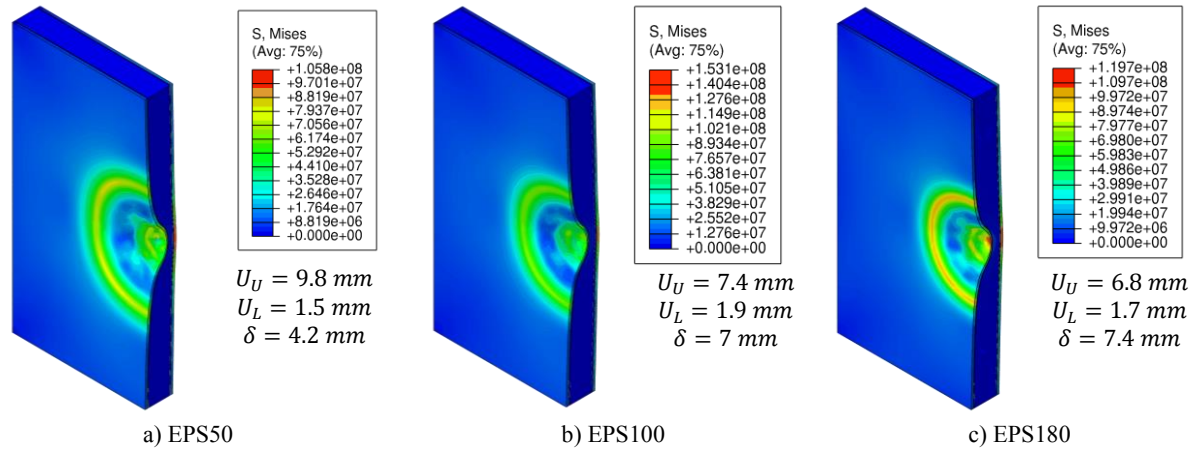
Impact tests were performed for impact energies of 20, 40 and 80 J, respectively. The impactor was hemispherical tip geometry of 20 mm in diameter, and 5 kg of a mass. The mechanical design parameter of foam core density was investigated to improve the impact energy absorption capability of the structure. The temporal variations of the contact force and the permanent deflections at the top and bottom surfaces were determined for three impact energy levels of 20, 40 and 80 J, respectively. The kinetic energies were evaluated to determine the energy absorption capability of structures. The specimen thickness is 12.5 mm for the all specimens. The permanent deflections were evaluated at the top surface of upper face-sheet ( $u_U$ ) and the bottom surface of the lower face-sheet ( $u_L$ ) in order to determine the energy absorption capability of the specimens.



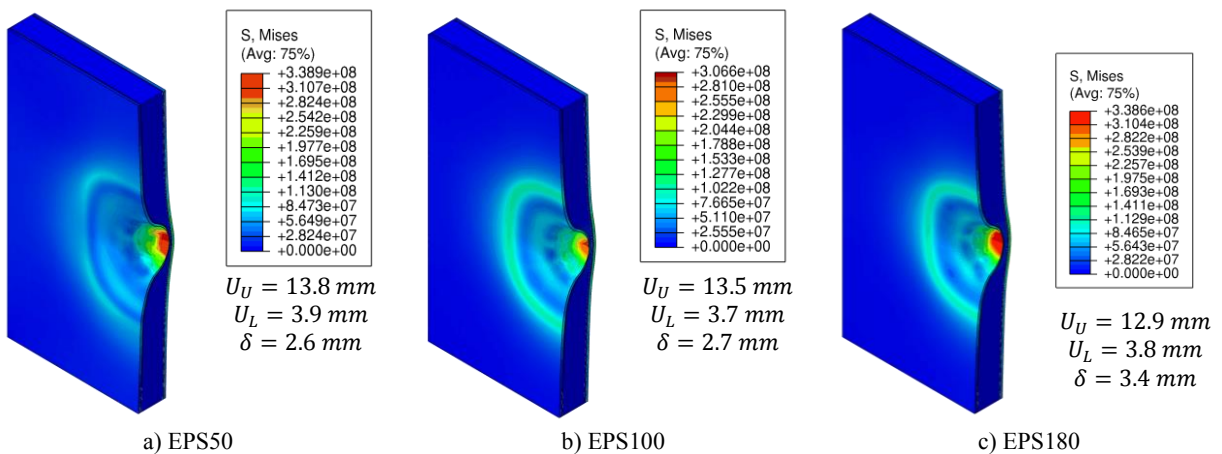
**Figure 3.** The effect the foam core density on the stress distribution and after-impact thickness of the central impact region for the impact energy of 20 J.

Figures 3-5 show the effect of the foam core density on the central transverse deflection of the central impact region for the impact energy level of 20, 40 and 80 J, respectively. As the foam core density is increased, the central

permanent deflections are decreased. The specimens with a foam core density of 50, 100 and 180 kg/m<sup>3</sup> have central permanent deflections  $u_U$  of 6.6, 6.5 and 5.8 mm at the top surface and  $u_L$  of 0.5, 1 and 0.8 mm at the bottom surface and the after-impact thicknesses of  $\delta = 6.4, 7$  and 7.5 mm for the impact energy of 20 J, respectively. The specimens with foam core densities of 50, 100 and 180 kg/m<sup>3</sup> have central permanent deflections  $u_U$  of 9.8, 7.4 and 6.8 mm at the top surface and  $u_L$  of 1.5, 1.9 and 1.7 mm at the bottom surface and the after-impact thicknesses of  $\delta = 4.2, 7$  and 7.4 mm for the impact energy of 40 J, respectively. The specimens with foam core densities of 50, 100 and 180 kg/m<sup>3</sup> have central permanent deflections  $u_U$  of 13.8, 13.5 and 12.9 mm at the top surface and  $u_L$  of 3.9, 3.7 and 3.8 mm at the bottom surface and the after impact thicknesses of  $\delta = 2.6, 2.7$  and 3.4 mm for the impact energy of 80 J, respectively.

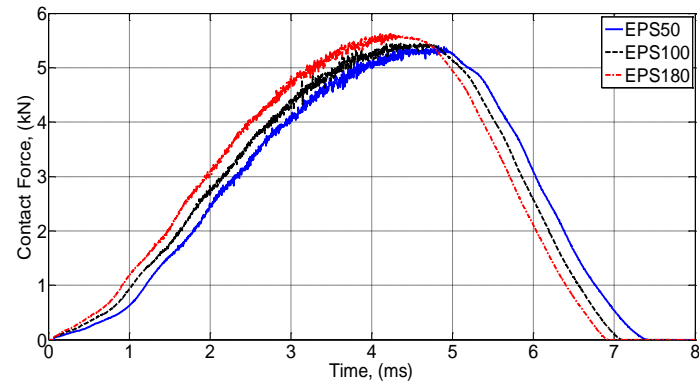


**Figure 4.** The effect the foam core density on the stress distribution and after-impact thickness of the central impact region for the impact energy of 40 J.

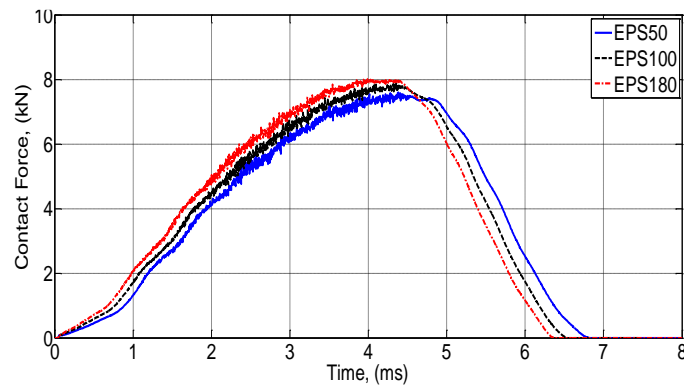


**Figure 5.** The effect the foam core density on the stress distribution and after-impact thickness of the central impact region for the impact energy of 80 J.

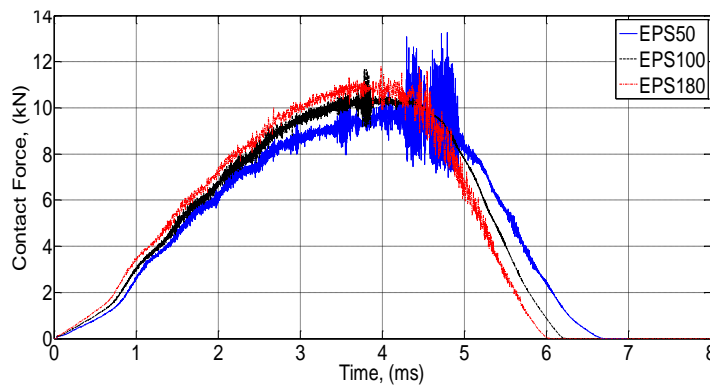
Figure 6 shows the effect of the foam core density on the temporal variations of the contact force under impact energies of 20, 40 and 80 J. The peak contact forces are measured as 5.38, 5.45 and 5.64 kN under the impact energy level of 20 J for foam densities of 50, 100 and 180 kg/m<sup>3</sup>, respectively, and the corresponding peak contact times are 4.67, 4.4 and 4.2 ms. The impact tests are completed in the total contact times of 7.4, 7.1 and 6.8 ms.



a)  $E=20\text{ J}$



b)  $E=40\text{ J}$

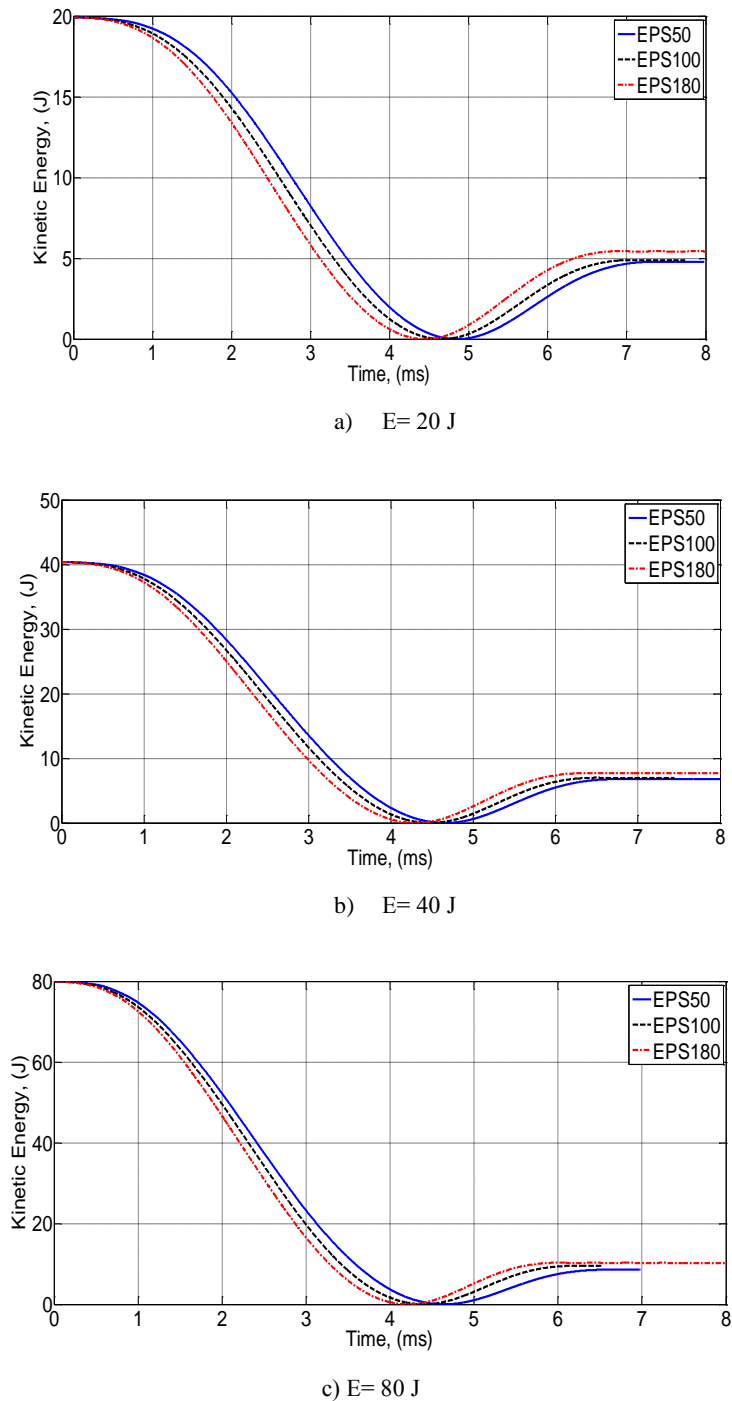


c)  $E=80\text{ J}$

**Figure 6.** The effect of the foam core thickness on the contact force histories for the impact energies of 20, 40 and 80 J.

For the impact energy level of 40 J, the variations of contact forces are measured as 7.5, 7.91 and 8.1 kN for a foam densities of 50, 100 and 180 kg/m<sup>3</sup>, respectively and the corresponding peak contact times are 4.3, 4.12 and 4.08 ms. The impact tests are completed in total contact times of 6.8, 6.5 and 6.3 ms. For the impact energy level of 80 J, the variations of contact forces are measured as 13.2, 11.6 and 11.8 kN for a foam densities of 50, 100 and 180 kg/m<sup>3</sup>, respectively and the corresponding peak contact times are 4.72, 3.7 and 3.9 ms. The impact tests are completed in total contact times of 6.7, 6.2 and 6.0 ms. As the impact energy is increased, the peak contact force levels are increased and the total contact durations are decreased. And also, the peak contact force levels are increased with increasing the foam core density. The total contact durations are decreased with increasing the foam core density for all impact energy levels. As the impact energy level becomes 80 J, upper face-sheet and lower face-sheet of the specimen with lowest foam core density come into contact and foam core tightens almost

completely so, the peak contact force levels are increased and the corresponding contact time changes. As the foam core density is increased, this situation changes and the foam core tightens less. Consequently, the changing foam core density does not affect precisely contact force histories.

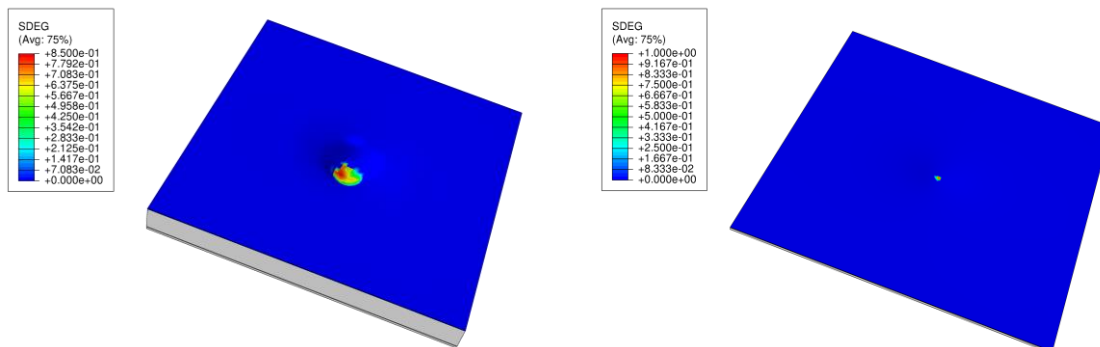


**Figure 7.** The effect of the foam core thickness on the kinetic energy histories for the impact energies of 20, 40 and 80 J

Figure 7 shows the temporal variations of kinetic energy for the specimens having different foam core densities under the present impact energies, respectively. The specimens with having foam core densities of 50, 100 and 180  $\text{kg/m}^3$  reduce impact energy of 20 J to kinetic energy levels of 4.7, 4.9 and 5.42 J, respectively; thus, the impact energies are dissipated by 76.5, 75.5 and 72.5%, respectively. The specimens under impact energy of 40 J have kinetic energy levels of 6.75, 7.1 and 7.78 J, respectively; thus, the impact energies are dissipated by

83.12, 82.25 and 80.1%, respectively. The specimens with having foam core densities of 50, 100 and 180 kg/m<sup>3</sup> reduce impact energy of 80 J to kinetic energy levels of 8.56, 9.5 and 10.5 J, respectively; thus, the impact energies are dissipated by 89.3, 88.1 and 86.8%, respectively. As the impact energy increased the penetrations times decreased for all specimens. The capability of absorbing kinetic energy is increased with decreasing foam core density.

The damage in adhesive layer occurs only in the specimen with having 50 kg/m<sup>3</sup> foam core density and impact energy level of 80 J. Figure 8 shows the damage area in the first and second adhesive layer of the specimen with having 50 kg/m<sup>3</sup>. There is no damage in the other specimens. Increasing the foam core density prevents damage and damage evolution.



**Figure 8.** Damage area of the specimen with having 50 kg/m<sup>3</sup> foam core density for the impact energy level of 80 J.

## CONCLUSION

This study presented the impact response of expanded polystyrene foam (EPS) core sandwich panels for different core densities of various impact energies. The temporal variation of contact force, kinetic energy histories and the permanent deflections at the top and bottom surface of sandwich panels assessed for the impact energies of 20, 40 and 80 J. Cohesive zone model (CZM) implemented simulations to model adhesive layer. Panels with lower core density absorbed more much energy. Minimum contact force appeared for the panels with lower foam core density and minimum central deflections appeared for the panels with higher foam core density. But, although there is quite difference between foam core densities, there is no quite difference between impact behavior parameter such as contact force and kinetic energy histories.

## NOMENCLATURE

EPS	Expanded polystyrene
PVC	Polyvinyl chloride
CZM	Cohesive zone model
E	Modulus of elasticity
G	Shear modulus
$t_n^0$	Traction in normal direction
$t_s^0$	Traction in shear direction
$G_n^0$	Stiffness in normal direction
$G_s^0$	Stiffness in shear direction
J	Joule
$U_U$	Central permanent deflection in upper plate
$U_L$	Central permanent deflection in lower plate
$\delta$	After impact thickness of the panel

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