RESPONSE OF FLEXIBLE SANDWICH PANELS TO BLAST LOADING

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Abstract

This paper reports on experimental and numerical investigations into the response of flexible sandwich panels when subjected to blast loading. The response of sandwich panels with steel plates and polystyrene cores are compared to panels with steel face plates and aluminium honeycomb cores. Panels are loaded by detonating plastic explosive discs in close proximity to the front face of the panel.

The numerical model is used to explain the stress attenuation and enhancement of the panels with different cores when subjected to blast induced dynamic loading. The permanent deflection of the back plate is determined by the velocity attenuation properties (and hence the transmitted stress pulse) of the core. Core efficiency in terms of energy absorption is an important factor for thicker cores. For panels of comparable mass, those with aluminium honeycomb cores perform "better" than those with polystyrene cores.

1 Introduction

Cellular materials, such as metal foams, polymeric foams, honeycombs and lattices have been proposed as cores for sandwich structures as they have improved plastic energy absorbing characteristics. The magnitude of the force transfer is controlled by the characteristic stress-strain curve of the cellular material under compression, an example of which is shown in Fig. 1. Generally, cellular materials attenuate blast-induced loads by cell collapse mechanism for low pulse pressure intensities when the stress transmission in a cellular material is limited by the plateau stress before the densification. However, stress enhancement may occur when an intensive loading is applied, which could produce a higher pressure on the back plate. Therefore, the transmitted force can attain high values due to the dynamic stress enhancement [1]. The variation of the equivalent panel mass and stiffness when varying the core properties can affect the dynamic response of the panel as a whole. It is therefore important to find an optimal core configuration by matching the properties of the cellular material [2].

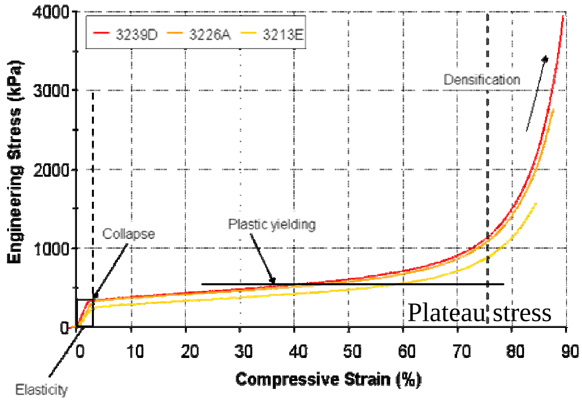


Fig. 1. Typical stress strain curves for cellular materials (Polystyrene, density = 32 kg/m^3, thickness 13, 26 and 39 mm)

For blast resistant applications, Hanssen *et al* [3] have investigated the response of aluminium foam, on a rigid back plate, to close range explosions. Foam offered the potential to take the impulse arising from the relatively short duration, high pressure shock front and modify it for transmission through the foam (or in fact, any cellular material) into a longer duration, lower magnitude force. This offers potential for controlled energy absorption and reduced force transfer compared to equivalent solid plates, although the mechanisms of shock transfer are not fully understood [3]. For practical sandwich panels, the back plate cannot be rigid and the influence of this flexibility on the overall response of the panel must be assessed [2, 4].

This paper reports experimental and numerical results on sandwich panels with flexible front and back plates. The main point of interest in this study is the analysis of the effect of the core properties, such as density, stress characteristics and thickness, on the response of the panel.

2 Experimentation

Sandwich structures with different cores comprising either polystyrene foam (*PS1*, *PS2* and *PS3*, with densities of 16, 24 and 32 kg/m^3 respectively) or aluminium honeycomb (HC with density 71 kg/m^3) are examined experimentally. The experiments on honeycomb core sandwich panels have been reported in detail in [5]. Quasi-static compression tests were performed on samples cut from the polystyrene and honeycomb core materials. The curves were all of the typical form exhibited by a foam material, with a linear elastic region, a plateau (plastic yielding) region and a densification region. A set of typical results is shown in Fig. 1 for the 32 kg/m^3 density polystyrene, with varying thickness. Properties varied little with thickness, as shown, for example for PS3 in Fig. 1. Properties for additional polystyrene foams (*PS4* and *PS5*) were obtained from [6] for the numerical study. Material properties are listed in Table 1.

Table 1. Engineering strain-strain characteristics of the core materials

Material	*PS1*	*PS2*	*PS3*	*PS4*	*PS5*	*HC*
ρ_0, kg/m^3	16	24	32	61	112	71
			σ, MPa			
ε = 0.1	0.055	0.114	0.365	0.456	0.936	2.400
ε = 0.2	0.073	0.147	0.402	0.495	1.110	2.433
ε = 0.3	0.091	0.165	0.439	0.568	1.276	2.447
ε = 0.4	0.119	0.202	0.504	0.620	1.520	2.467
ε = 0.5	0.147	0.229	0.567	0.720	1.780	2.473
ε = 0.6	0.183	0.284	0.658	0.880	2.370	2.487
ε = 0.7	0.266	0.385	0.841	1.320	3.850	2.500
ε = 0.8	0.440	0.551	1.390	2.190		8.700

Blast tests were performed using steel plates with polystyrene and honeycomb cores clamped in a circular frame, as shown schematically in Fig. 2. The polystyrene cores were 13, 26 and 39 mm thick, and the honeycomb cores were 13 mm thick. A test matrix is shown in Table 2. The plates were not adhered to the core, so that the energy absorption due to debonding of the components could be discounted. All specimens had a circular exposed area of diameter 106 mm. The test specimens were clamped in the test rig and mounted onto a pendulum, as shown in Fig. 3.

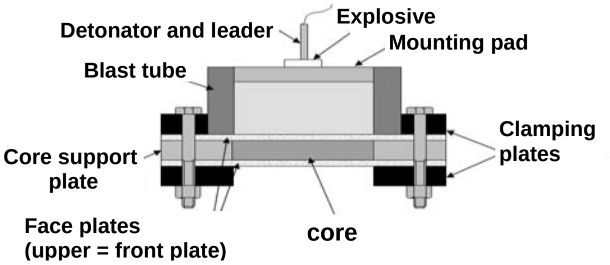
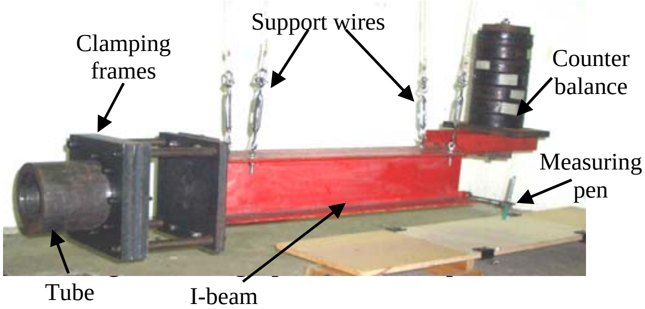


Fig. 2. Schematic of blast test arrangement

Table 2. Test Matrix

Core Type	Thickness (mm)	Core Density (kg/m^3)	No. of tests	Impulse range (Ns)
Polystyrene	13, 26, 39	16, 24, 32	57	2-40
Aluminium honeycomb	13	71	16	7-41

A 150 mm long tube with the same internal diameter as the clamping frame (106 mm) was attached to the front of the clamping rig. The PE4 was moulded into a 34 mm diameter disc and sited at the open end of the tube. The detonator was attached to the centre of the disc using 1g of explosive, referred to as a ‘leader’. A tube was used between the explosive and target plate to improve the spatial uniformity of the blast loading incident on the target plate, as described by Jacob *et al* [7]. The impulse was obtained using the measured swing of the pendulum. The permanent deflection of the plates and core thickness changes were measured.



3 Blast Test Results

3.1 Polystyrene Cores

Selected results from the blast tests conducted on sandwich structures with a various thickness polystyrene cores are presented in Fig. 4 and 5 as displacement-impulse graphs. Trend-lines are not included in these figures because of the range of core thicknesses that would be obscured by the lines.

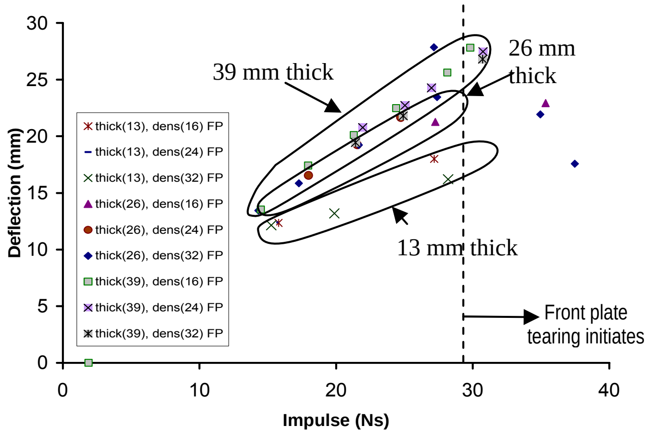


Fig. 4. Displacement of the front plate vs. impulse for sandwich plates with polystyrene cores

There are two phases of interaction evident in the polystyrene core sandwich panels:

Phase 1: Front plate deformed, with mid-point deflection increasing with increasing impulse, but with no measurable deformation of the back plate. Polystyrene cores have a very low plateau stress and transmitted little force through to the back plate. The crush profile of the polystyrene resembled that of the front plate deformation, with the maximum crushing in the centre, decreasing radially outwards. This phase ends when the core began to densify and transmit larger forces to the back plate, hence the thickness of the core determined the impulse threshold at which this occurs. From Fig. 5 it is observed that non-zero permanent deformation of the back plate initiates at higher impulses with increasing core thickness. From Fig. 5(b), it is observed that significant back plate deformation is evident only after tearing of the front plate in the 39 mm thick core panels, at impulses above 30 Ns.

Phase 2: The front plate deflections increased and the polystyrene core densified; the larger stresses transmitted through to the back plate caused permanent deformation of the back plate, which increased with increasing impulse. The front plate tore once the deflection reached a peak of approximately 28 mm. This is similar to the deformation observed by Teeling Smith and Nurick [8] for single blast loaded 1.6 mm thick mild steel plates. In [8], deflection increased with increasing impulse up to a peak (29 mm at 28 Ns) just prior to mode II* failure – once tearing occurred the deflections decreased linearly with increasing impulse as most of the energy available to strain the plate was used in the tearing process. The impulses and displacements at the point of front plate tearing are similar in these experiments, however, initiation of tearing occurs at higher impulses in the panels with 39 mm thick cores. There are a couple of outlying datapoints that are associated with variation in the response of the panels at the tearing threshold.

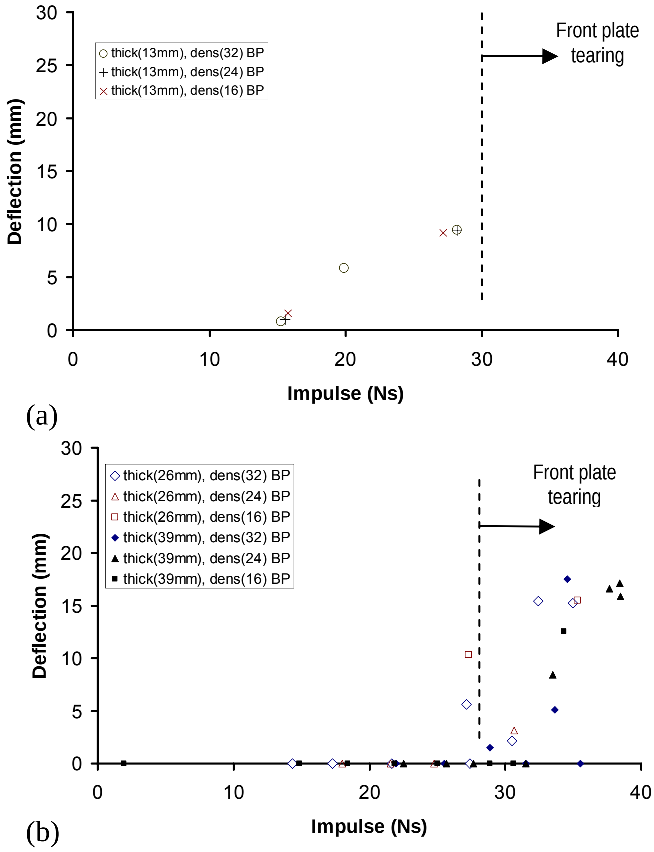


Fig. 5. Displacement of the back plate vs. impulse for sandwich plates with polystyrene cores. (a) 13mm and 26 mm thick core; (c) 39mm thick core.

3.2 Honeycomb cores

The results from selected blast tests performed on sandwiches with honeycomb cores are presented in Fig. 6. For full details see Ref [5]. Here, there are three phases of interaction:

Phase 1: The front and back plates exhibited large plastic displacements with profiles that are typical of uniformly loaded circular (single) plates. Photographs of selected plate profiles are shown in

Figs. 7(a) and 7(b). The honeycomb core also exhibited permanent global displacement due to bending, as shown in the photograph of a typical honeycomb core in Fig. 7(c), and crushing/micro-buckling within the cells. As the impulse increased, the central displacement of both plates increased as the honeycomb was able to transmit load through the cell structure to the back plate. An example of this is shown in Fig. 7(b). At impulses up to approximately 28 Ns, the front and back plate displacements increase linearly with increasing impulse. The front plate displacement increases more rapidly than the back plate displacement with increasing impulse.

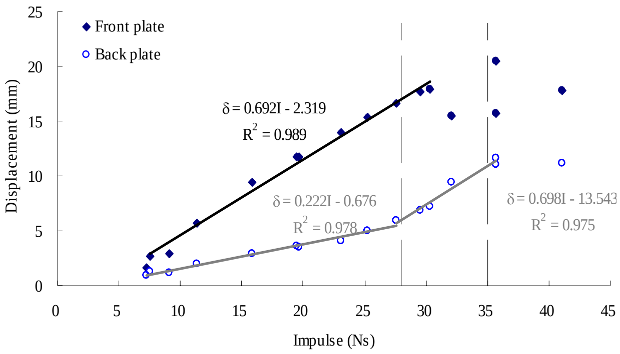
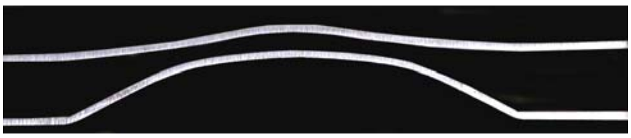


Fig. 6. Graph of displacement vs impulse for sandwich panels with honeycomb cores

(a)



(b)

(c)

Fig. 7. Typical responses of sandwich panels. (a,b) Steel plate profiles (back plate at the top), (a): I_0 = 13.3 Ns, (b): I_0 = 22.3 Ns; (c) Honeycomb core, I_0 = 30.3 Ns

The spatial distribution of the honeycomb crushing varied with the displacement of the plates, with the maximum crush distance in the centre with decreasing crush distance radially outwards. At 28 Ns impulse, the honeycomb crushed to its maximum stroke (approximately 11 mm) in the centre.

Phase 2: The front plate displacement is fairly constant during phase 2, as partial and complete tearing failures initiate at the boundary. The displacement of the back plate increases more rapidly than during phase 1, as more load is transmitted through the compressed honeycomb. The area of the honeycomb core that has crushed to its maximum limits increased in size with increasing impulse, for the impulse range of 28 to 35 Ns – a photograph of a typical honeycomb core is shown in Fig. 7(c).

Phase 3: At higher impulses (over 35 Ns) the front plate is exhibiting complete tearing failure more consistently than in the 30 to 35 Ns range. In the 35 to 40 Ns range, the back plate displacement has reached a plateau and partial tearing is observed at an impulse of 40 Ns. The whole of the honeycomb is crushed to its limit at 40 Ns. This indicates that the honeycomb can no longer contribute to energy absorption.

4. Numerical analysis

4.1 Response of a panel with a polystyrene core

FE models using ABAQUS/Explicit were formulated for sandwich panels consisting of mild steel face sheets with thickness h = 1.6mm and cores with thicknesses c = 13 mm, 26 mm and 39 mm made of polystyrene with different properties listed in Table 1. In order to increase the range of the analysed core properties, polystyrene materials *PS4* and *PS5* [6] are considered in addition to the tested polystyrene types, *PS1*, *PS2* and *PS3*. The static stress-strain characteristic for the particular mild steel is given in Table 3 while the strain rate sensitivity is taken into account as a power law function with D = 40.4s^{-1} and q = 5.

Table 3. Static engineering stress-strain relationship

ε	0.0009	0.005	0.01	0.02	0.03	0.04
σ, MPa	180	230.8	235.6	235.3	247.6	264.6
ε	0.05	0.1	0.2	0.3	0.4	
σ, MPa	276.5	305.8	320.4	324.8	325.6	

Circular plates with diameter 106 mm clamped at the edges are considered under blast loads large enough to produce substantial deflections as described in the previous sections. The plates and the core are not bonded together, so that separation can occur during the response. The uniformly distributed blast loading is applied as a pressure pulse on the top surface of the sandwich structure. The pressure

$$p(t) = p_0 e^{-t/t_0} \quad (1)$$

decays exponentially with a decay period of t_0 = 0.05ms. The different pressure pulses are defined due to the momentum conservation

$$I_0 = \pi R^2 \int_0^\infty p(t)dt \,. \quad (2)$$

The impulses are varied between 14Ns and 32Ns. The partial or complete tearing along the clamped boundary of the front plate, which was observed in the experiments for the higher impulses, has not been included in the numerical model.

Due to the symmetry of the problem, only a quarter of the sandwich panel is modelled with the appropriate symmetry conditions at the boundaries (Fig. 8). Shell elements S4R are used to model the plates but solid elements C3D8R (8 nodes reduced integration) are used for the core material. The typical element size has a side dimension of 1 mm. 'CRUSHABLE FOAM' material model was used to describe the stress-strain relationship for the different types of polystyrene.

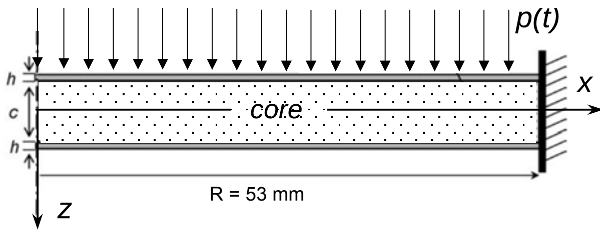
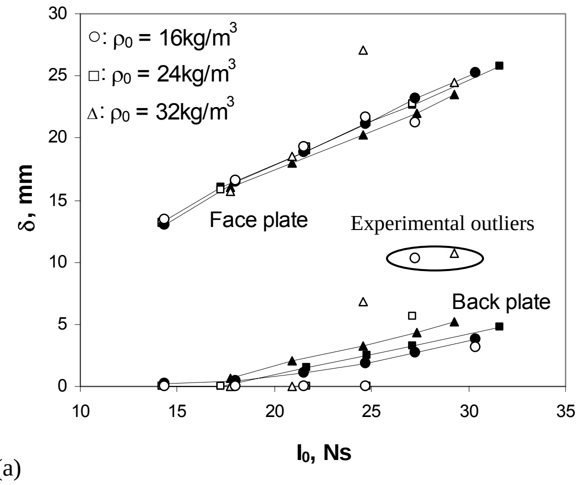


Fig. 8. FE model

The resistance to blast loading is quantified by the permanent transverse deflection, δ, at mid-span of the plates as a function of the applied load. Comparisons between the experimental test results and the numerical predictions for a panel with a core thickness of 26mm and 39mm are shown in Fig. 9. The results correlate reasonably well, with the exception of the outlying points (marked on Fig. 9) from the experiments associated with the tearing threshold. No comparison between the measured compression, Δc, at the mid-span of the core and the numerical predictions has been made due to the significant relaxation of the polystyrene inserts after disbanding the tested panels. The simulation of the response of the double-face structure with the air gap was performed for gaps of 13 mm and 26 mm to verify the strain-rate effects on the steel plates under blast loadings.

Generally, cellular material attenuates impact or blast-induced loads by cell collapse mechanism at low impact velocities or low pulse pressure intensities when the stress transmission in a cellular material is limited by the plateau stress before the densification stage starts. However, stress enhancement in cellular material may occur when an intensive loading is applied, which could produce a higher pressure on the back plate. Therefore, the transmitted force can attain quite high values due to the dynamic stress enhancement [1].

The main point of interest in this study is the analysis of the effect of the core properties, such as density, stress characteristics and thickness, on the response of the panel. Due to the small weight fraction of the core in comparison to the entire sandwich panel, negligible variations of the induced velocities in the front plate of the polystyrene panels occur for equal impulses.



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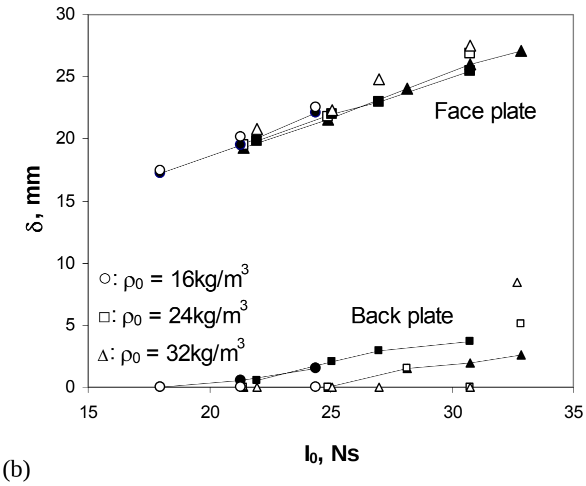
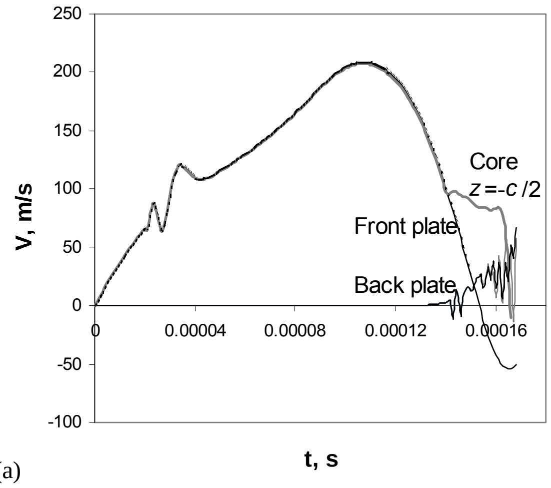


(b)

Fig. 9. Comparison between the numerical and experimental results; (a) c = 26 mm; (b) c = 39 mm (the open symbols mark the experimental results; the closed symbols show the numerical results).

In some theoretical studies [9] an idealisation of the blast loading is assumed describing the blast only by its integral characteristic, the impulse I_0, which determines a finite initial velocity. The actual blast loading can be more accurately approximated however, as a pulse loading with a finite duration, Eq (1), which causes a certain velocity-time profile on the front plate. Moreover, considerable deformations of the panel can develop within the pulse duration. This is particularly true for stocky sandwich beams and panels, which are analysed in the present study. The resulting velocity profile of the front plate, which cause core deformation is history dependent and is related to the deformation of this plate when the maximum velocity occurs at the centre of the plate.



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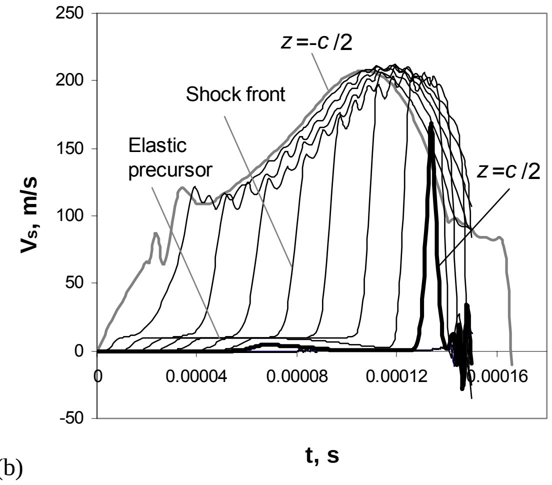


(b)

Fig. 10. Typical velocity-time history, I_0 = 21.76 Ns; c = 26 mm, *PS2*. (a) Velocity at the mid-span of the front plate, back plate and the core faces;
(b) Velocities at the shock front – particle velocities at several points across the core thickness (0,0, z).

Due to the high compressibility of the polystyrene materials and aluminium honeycombs, blast loadings with high intensity cause large deformations in the core due to the propagation of stress shock waves trough the thickness. Different stress pulses are transmitted to the back plate depending on the intensity of the load and core characteristics. A typical variation of the velocity at the mid-span of the front and back plates due to 21.76Ns impulse are shown in Fig. 10(a). It is observed that after equalization, the velocities of the back and front plates vary in different manners due to the separation of the front plate from the core, while the core and the back plate continue to move together.

The particle velocities at some points across the core thickness (0,0,z), $z \in [-c/2, c/2]$ are shown in Fig. 10(b) where it is evident that it is a typical transient deformation process of the sandwich core. The deformation at this particular section of the core can be considered to be in a nearly uniaxial stress state and the effective sound velocity in a foam material can be defined as [10]

$$c_s^2 = \left| \frac{1}{\rho_0}\left(\frac{d\sigma(\varepsilon,\rho_0)}{d\varepsilon}\right)\right|, \qquad (3)$$

where $\sigma(\varepsilon,\rho_0)$ is the static stress characteristic and ρ_0 is the initial material density. Shock waves occur in a foam material, when the impact velocity is larger than c_s [10]

$$c_s = \left(\frac{1}{\rho_0}\frac{(\sigma_D-\sigma_{cr})}{(\varepsilon_D-\varepsilon_{cr})}\right)^{1/2}, \qquad (4)$$

where ε_{cr} is the strain corresponding to the initial crush stress σ_{cr}; ε_D is the densification strain, defined as [11]

$$\varepsilon_D = \left.\frac{dE}{d\varepsilon}\right|_{\varepsilon=\varepsilon_D}, \quad E(\varepsilon_a) = \frac{1}{\sigma(\varepsilon_a)}\int_0^{\varepsilon_a}\sigma(\varepsilon)d\varepsilon \,. \ (5a,b)$$

The minimum effective sound velocity associated with the plateau stresses of the analysed polystyrene materials is about 100 m/s while c_s attains values between 175 m/s and 192 m/s.

The blast loadings discussed in the present study induce velocities between 200 m/s and 280 m/s at the mid-span of the front plate, so that the deformation of the core material is characterised by the propagation of the shock wave and therefore can be analysed accordingly. The propagation of an elastic precursor wave is evident in Fig. 10(b) before the major velocity jump occurs at a certain point of the core cross section. The thicker curve in this figure characterises the arrival time and the velocity magnitude at the core layer (1mm thick), which is in contact with the back plate. This particle velocity can be used to calculate the dynamic stress enhancement, $\Delta\sigma$, of the incident stress, σ_I

$$\sigma_I = \sigma_{cr} + \Delta\sigma, \quad \Delta\sigma = \rho_0 (V_s - V_b)^2 / \varepsilon_D, \quad (6a,b)$$

where V_s is the particle velocity in the core layer, V_b the velocity of the back plate. The transmitted and reflected stress can be calculated using the stress transformation formula [12]

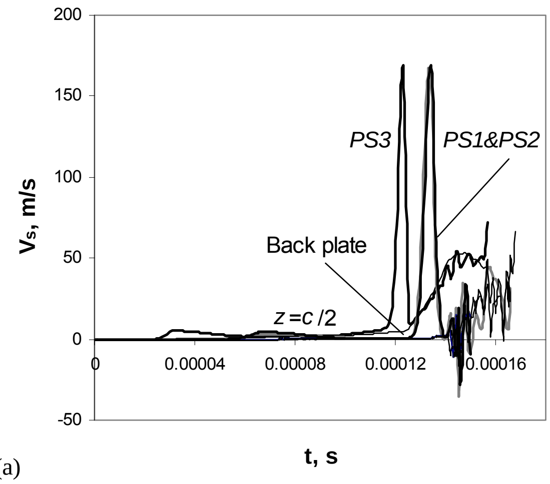
$$\sigma_T = \frac{2c_b\rho_b}{c_s\rho_c + c_b\rho_b}\sigma_I, \sigma_R = \frac{c_b\rho_b - c_s\rho_c}{c_s\rho_c + c_b\rho_b}\sigma_I, \quad (7a,b)$$

where c_s, $\rho_c > \rho_0$ are the characteristics of the core (ρ_c is the current core density) and c_b, ρ_b are the characteristics of the back plate material.

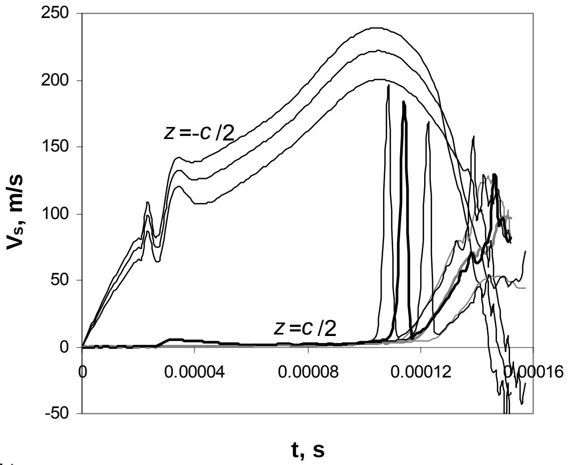
For the particular material parameters, the transmitted stress pulse is

$$\sigma_T \approx 2\sigma_I, \quad \sigma_R \approx \sigma_I \quad (8a,b)$$

due to $c_s\rho_c << c_b\rho_b$.



(a)

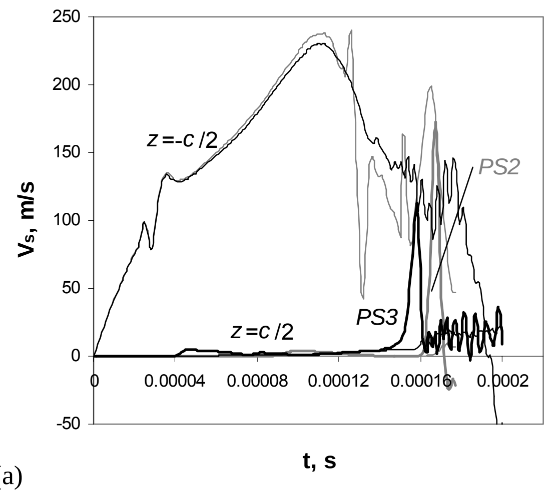


(b)

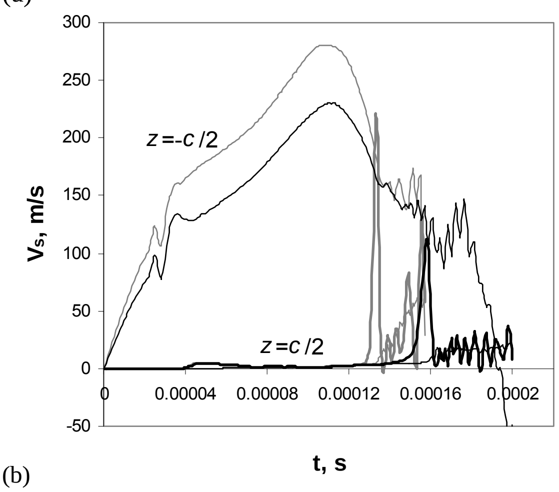
Fig. 11. Particle velocities in the core at (0,0,$z = c/2$), c = 26mm; (a) I_0 = 21.76Ns, *PS1*, *PS2* and *PS3*; (b) *PS1*, I_0= 21.76Ns, I_0 = 24.78Ns and I_0= 27.16Ns.

In the further analysis, the shock front velocity is used as a characteristic parameter to compare the response of the panels with different core materials. The shock front velocities in a 26mm thick core are compared in Fig. 11(a) for polystyrene with different densities. All three velocities for materials *PS1*, *PS2* and *PS3* are comparable except that the shock front propagates faster in the polystyrene core *PS3*. Therefore, the dynamic enhancement of the incident stress pulse is proportional to the material density and the largest transmitted stress is caused by the core material *PS3*. This result is in agreement with the observation (Fig. 9(a)) that largest permanent deflections of the back plate occur for material with the highest density, *PS3*.

The increase of the blast intensity induces larger velocity of the front plate thus causing larger velocities of the shock front. Moreover, the shock front travels at a higher speed for the larger loads (Fig. 11(b)), and consequently larger stresses are transmitted to the back plate.



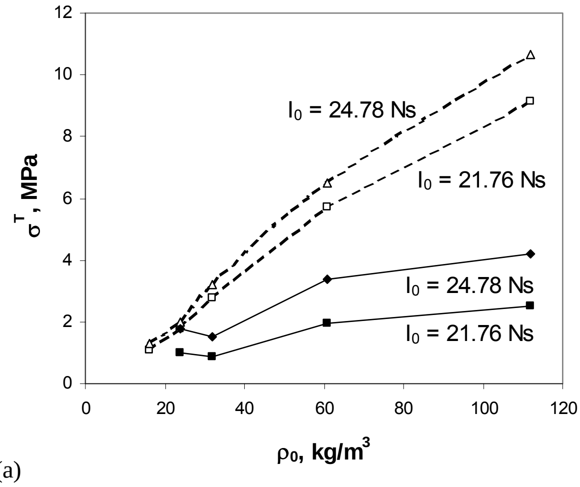
(a)



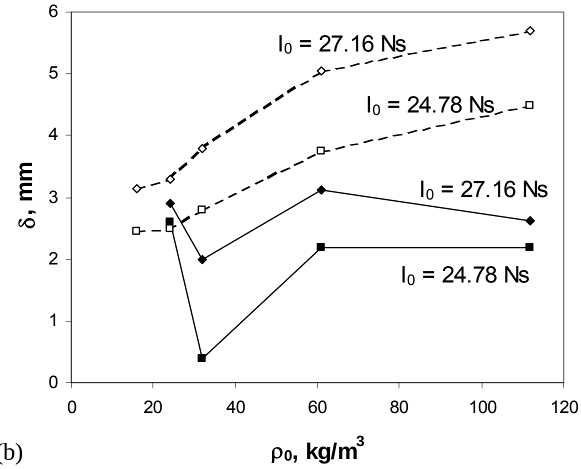
(b)

Fig. 12. Particle velocities in the core at (0,0,$z = c/2$), c = 39mm; (a) I_0 = 24.78Ns, *PS2* and *PS3*; (b) *PS3*, I_0 = 24.78Ns and I_0 = 31.59Ns.

A different relationship between the material properties and the permanent deflections of the 39 mm thick core is observed from the numerical simulations. The smallest displacements are associated with material *PS3* as shown in Fig. 9(b). A comparison between the shock front velocity in polystyrene cores made of *PS2* and *PS3* is shown in Fig. 12(a). It is evident that the particle velocity V_s in material *PS3* is considerably lower than the corresponding velocity in material *PS2*. Therefore, the stress enhancement due to the identical blast loadings is smaller in material *PS3.* Similarly to the response of the 26mm thick core, the increase of the blast intensity causes an increase of the particle velocity as shown in Fig. 12(b) and therefore larger stress pulses are transmitted to the back plate.



(a)



(b)

Fig. 13. Response of the back plate, c = 26mm: - - - ; c = 39mm: ——. (a) Transmitted stress at point (0, 0, $z = c/2$); (b) Permanent displacements of the mid-span of the plate.

The variation of the transmitted stresses to the back plate, which result from blasts with two different intensities, is shown in Fig. 13(a) for cores thicknesses of 26mm and 39mm. While the transmitted stress by the thinner core increases monotonically with the increase of the material density, a local minimum is observed for the thicker core made of material *PS3*. The corresponding permanent deflections of the back plate in Fig. 13(b) show the same behaviour.

Since the weight (and strength) fraction of the core is small in comparison to the entire sandwich panel, the permanent deflections resulting from a blast depend mainly on the induced velocities when relatively thin polystyrene inserts are used as no significant shock attenuation can be achieved. The results from the numerical simulations of blast loading on panels with 13 mm core show practically no difference in the permanent deflections for the different polystyrene types due to the small velocity attenuation in the core.

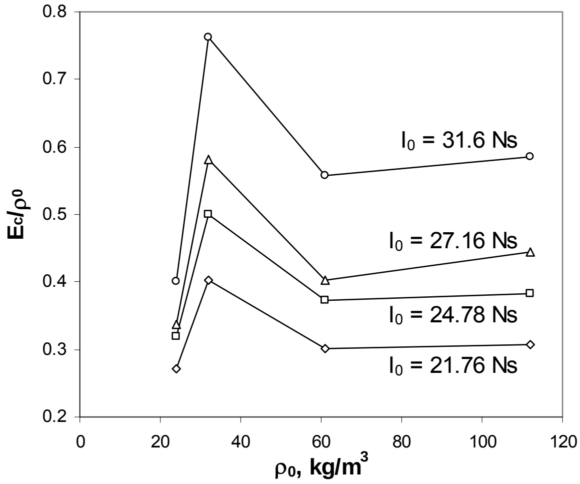


Fig. 14. Core efficiency, E_c/ρ_0 for different materials, c = 39 mm.

Relatively thick cores, however, can reduce the velocity jump at the shock front during the time while the stress wave propagates towards the back plate. In this case, the absorbed energy due to the core deformation is not negligible and the influence of the strength and density of the core material becomes more important. The core efficiency in terms of the energy, E_c, absorbed per unit mass can be referred to as a particular core characteristic. The variation of E_c/ρ_0 in Fig. 14 for a 39 mm thick core shows that material *PS3* is the most efficient core material analysed. It should be noted that a second shock front can propagate in the core due to the reflected stress pulse thus causing a further compression of the core and an increase of the absorbed energy. An increase of E_c/ρ_0 for material *SP5* at higher blast impulses reflects this phenomenon.

The significant effect of the dynamic stress enhancement in the core on the permanent deflections of the panel shows that the total impulse, I_0, is not a sufficient characteristic of the blast loading when studying the structural response. For a constant total impulse, a larger pressure corresponds to a shorter pulse. Therefore, short duration pulses cause larger velocities of the front plate and respectively in the core, which leads to a larger stress enhancement as shown in Table 4. As a result, the permanent deflections of the back plate of the panel increase (Fig. 15).

Table 4. Enhancement of the transmitted stress due to the decrease of the pulse duration, I_0=24.78Ns

	ρ_0, kg/m^3	24	32	61	112
		c = 26mm			
t_0=0.05ms	σ_T, MPa	1.980	3.196	6.478	10.677
t_0=0.025ms	σ_T, MPa	2.220	3.588	6.962	11.528
		c = 39mm			
t_0=0.05ms	σ_T, MPa	1.784	1.521	3.386	4.205
t_0=0.025ms	σ_T, MPa	1.931	2.685	4.505	6.201

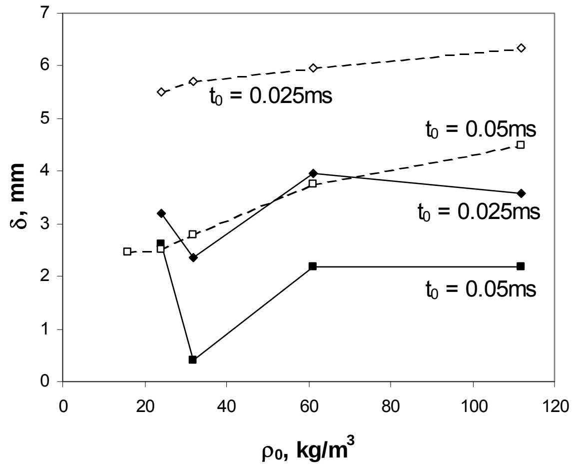


Fig. 15. Permanent displacements of the mid-span of the back plate for blast impulse I_0 = 24.76Ns applied as pulses with different duration, c = 26mm: - - - ; c = 39mm: ——.

4.2 Comparison between the responses of panels with polystyrene and honeycomb cores

The above discussion reveals that being a function of the velocity V_s, the stress pulse transmitted to the back plate depends on the velocity attenuation in the core, which turns out to be influenced by the core efficiency E_c/ρ_0. Thus, light materials with higher plateau stresses could have superior performance when used as core materials. The comparison between the responses of sandwich panels with 26 mm thick polystyrene (ρ_0= 61kg/m^3) and aluminium honeycomb cores (ρ_0 =71 kg/m^3) in Fig. 16(a) shows an advantage of the stronger core.

Small, almost constant, permanent displacements of the back plate are predicted for a large variation of blast loadings on the panel with the honeycomb core while impulses larger than about 21Ns cause larger deflections of the back plate of the panel with the polystyrene core.

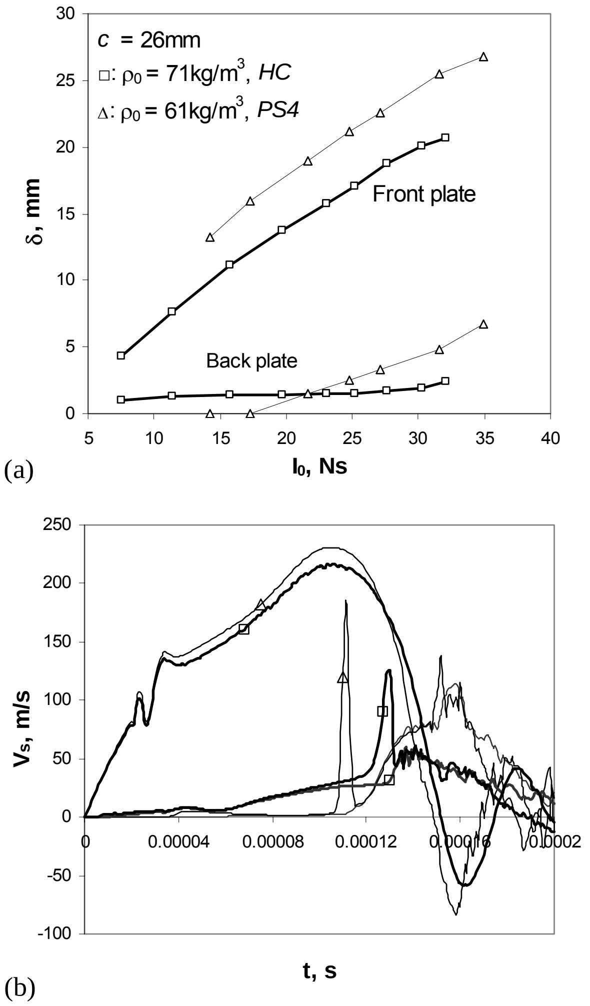


Fig. 16. Comparison between the responses of sandwich panels with aluminium honeycomb and polystyrene cores with similar densities, c = 26 mm. (a) Permanent displacement; (b) Particle velocities in the core at (0, 0, z = c/2), I_0 = 27.2 Ns.

The shock front velocity attenuation is shown in Fig. 16(b). The precursor stress wave carrying stresses equal to σ_{cr} causes a small velocity to the back plate of the honeycomb panel. However, the stress front propagates slowly and the velocity magnitude has decreased significantly when it reaches the interface between the core and back plate. On the other hand, the precursor wave in the polystyrene core causes a negligible velocity of the back plate but a higher velocity jump is observed close to the interface, which determines a significantly higher stress enhancement. As a result, the transmitted stresses from the honeycomb core, $\sigma_{T,HC}$ =6.15MPa is smaller than the stress transmitted by the polystyrene, $\sigma_{T,PS4}$ = 6.7MPa, so that, larger deflections of the back plate of the polystyrene panel develop (Fig. 16(a)).

The permanent deflections of the front plate of the panel with a polystyrene core are considerably larger then the deflections in the honeycomb panel over the entire range of the impulse variation due to the lower polystyrene strength. This can potentially lead to damage of the front plate for smaller impulses.

5 Conclusions

Experimental and numerical studies are carried out to analyse the effect of the core properties, such as density, stress characteristics and thickness, on the response of a sandwich panel to blast loading when considering very soft cores in comparison with the strength of the binding plates. It is found that the velocity attenuation through the core thickness, which influences the transmitted stress pulse to the back plate, determines the permanent deflections. The core efficiency in term of energy absorption is an important factor for thicker cores.

A comparison between the panels with a polystyrene and a aluminium honeycomb shows that the latter has better performance in terms of reduction of the initial pressure pulse.

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