

# **ADVANCED MATERIALS FOR ENHANCED AUTOMOTIVE SAFETY**

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## **ABSTRACT**

Safety is becoming an increasingly important subject for car manufacturers. This is due to legislation in the form of regulations such as FMVSS201, 208, and 214 for occupant protection, and recent proposals from Working Group 17 to the European Commission. Public awareness is also increasing through programmes such as EuroNCAP. The industry is increasingly using its products' safety features as a marketing tool.

To meet the present and increasing demand for enhanced safety in cars, the ideal energy absorber should work as a multi-functional element. It should also function as a structural component, a heat exchanger, an air filter, a liquid storage component, or an acoustic insulator. Other important considerations are the recyclability and minimisation of weight.

The ability of the absorber to give consistent results under various impact angles, its ease of manufacture, its performances under various environmental conditions and its ease of handling will all be of concern to the designer. Ease of modelling will also be required for accurate implementation of the countermeasure.

Sandwich structures can offer designers many of the above benefits. Traditionally, these were made from foams (PU and PP), plastic ribs or honeycomb materials, which are an interesting but expensive alternative.

In this paper, PressLoad is investigated in detail under a range of conditions, and we will be examining its performance relative to other commonly available materials, giving practical examples of how to apply it to critical locations within the car.

In addition, we will be discussing its use both as a primary component and as an add-on.

## **1. INTRODUCTION**

In the fifteen EU member states there are approximately 42,000 reported deaths and 1.5 million injured as a result of road accidents. Decisions to undertake counter measures are based on their casualty reduction potential. Identified short and medium term priorities are as follows:

- Continue and increase support for Euro NCAP
- Legislation on safer car fronts for pedestrians and cyclists

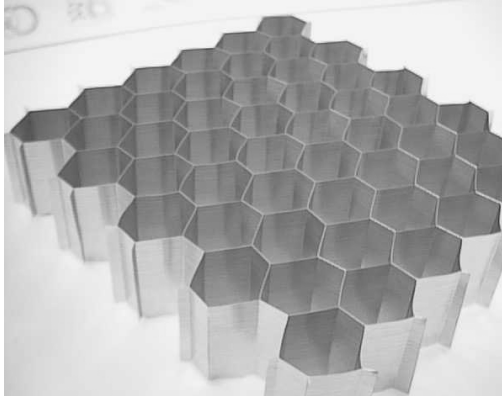
Much of the technical advice on vehicle secondary safety in Europe is developed by EEVC. The EEVC working group advises on various aspects of safety, and are currently looking at the following:

WG 13:	Side impact test procedure
WG 14:	Truck underrun
WG 15:	Car to car compatibility
WG 16:	Advanced frontal protection
WG 17:	Pedestrian protection

Energy absorbing materials are seen as a way of meeting many of the challenges that are faced by designers. Many in-house requirements surpass the proposed or legal requirements. Safety is used as an important marketing feature and is singled out as a major factor to gain customer loyalty. We look at ways of using PressLoad in meeting some of the challenges above.

## 2. THE ENERGY ABSORBER FAMILY

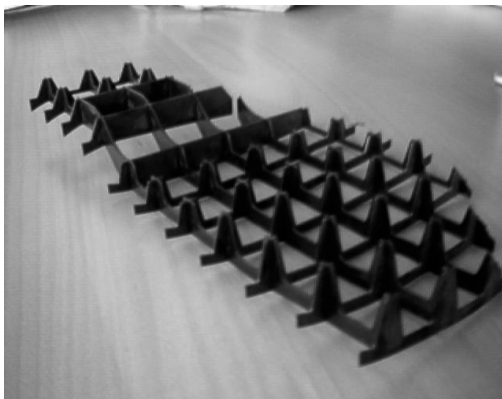
There are many materials currently available for energy absorbing applications. Some examples of these are shown in the pictures below.



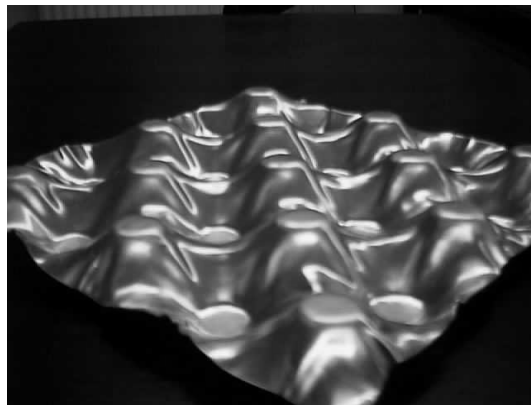
*Picture 1: Aluminium honeycomb*



*Picture 2: Standard rigid PU foam*



*Picture 3: Plastic ribs*



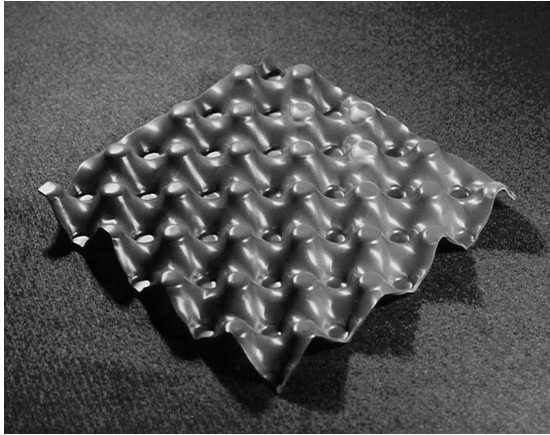
*Picture 4: PressLoad*

Picture 4 shows Cellbond's PressLoad absorber. This absorber uses a specially designed geometry, an arrangement of regular flat-top cones. It is a low cost component with excellent energy absorption capabilities and is most suitable for high volume production. The PressLoad absorber offers cost effective solutions for the car industry and is manufactured from a range of metallic sheet products (cold forming) or thermoplastic materials (thermoforming, injection moulding).

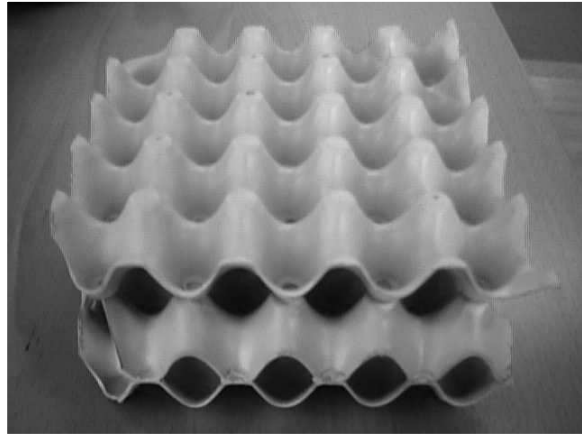
The shape of the structure, whether in its raw form or sandwiched, has the additional advantage of having an open structure along its length. This makes it possible for matter (gases, wiring etc) to pass along the length of the panel.

### 3. GEOMETRY AND PROPERTIES OF PRESSLOAD

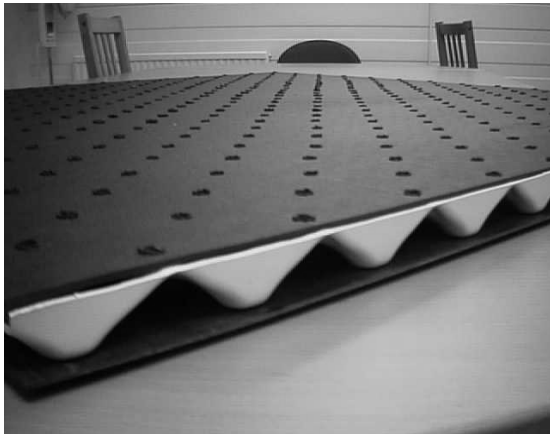
The PressLoad structure is based on a basic egg box shape. A simple PressLoad consists of evenly spaced flat top cones, however it is possible to tailor the shape for a given application. An example of this is shown in picture 8.



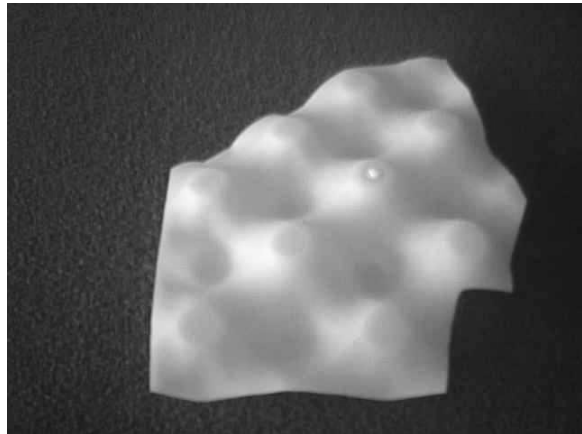
*Picture 5: Steel PressLoad*



*Picture 6: ABS sandwich structure*



*Picture 7: PP double skin structure*

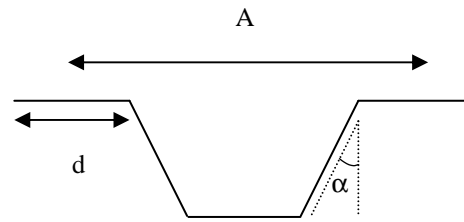
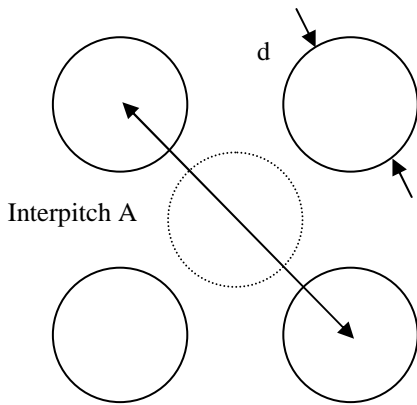


*Picture 8: PressLoad application example*

PressLoad can be made using a range of materials; Aluminium alloys, steel, PP, ABS, PC/ABS blend, PC and mesh materials. The parts are produced by cold or forming (thermoforming, injection moulding). Various methods can be used to join PressLoad parts, including adhesives, pierce riveting, clinching and welding.

#### 3.1 Moulds and geometry

Figure 1 shows how the PressLoad structure is defined. The properties of the structure can be adjusted by varying the interpitch, peak diameter and cell angle for a given material choice. Reducing the interpitch has a pronounced effect on the properties of the structure. This reduction gives a higher density of cones throughout the structure resulting in an increased stiffness and a higher plateau stress.

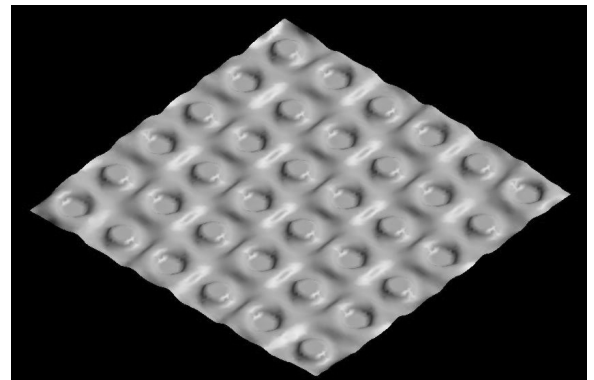
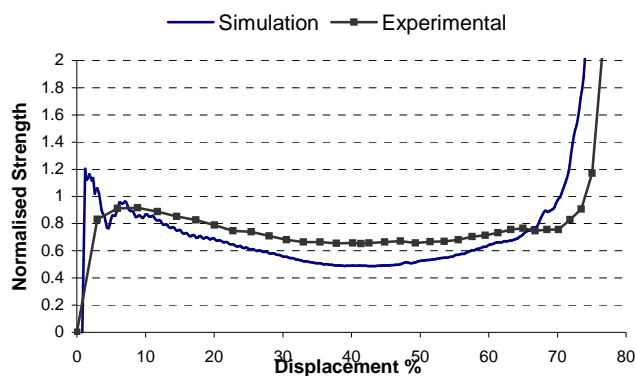


**Fig 1: PressLoad geometry**

### 3.2 Behaviour of PressLoad

Picture 9 shows the behaviour of PressLoad during a static crush test. The picture shows that a bending process occurs during the crush, and it is this mechanism that gives the plastic plateau. The theoretical limit for this plateau is about 65% elongation.

A dynamic simulation (LS Dyna) of the PressLoad absorber demonstrates all the intrinsic qualities of this geometry. The model can be constructed using surface data as defined by the geometry parameters in section 3.1. Graph 1 shows a simulation for a simple crush test.



**Graph 1: Compression test (velocity: 2 m/s)**

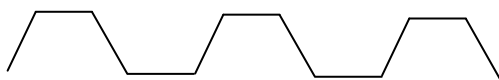
**Picture 9: Surface after compression**

The important features are as follows:

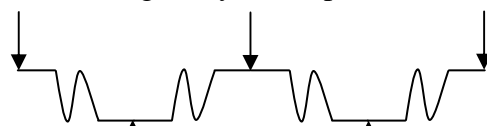
- No elastic peak
- A plastic plateau: energy absorption area
- An inflation at the end of the deformation (densification)

### 3.3 Theoretical deformation model

Figures 2 and 3 show a diagrammatic representation of the deformation mechanism of PressLoad. Figure 3 shows how the walls of each PressLoad cone collapses. It is this bending of the pitch structure that is responsible for the length and homogeneity of the plateau.



**Fig 2: Before testing**

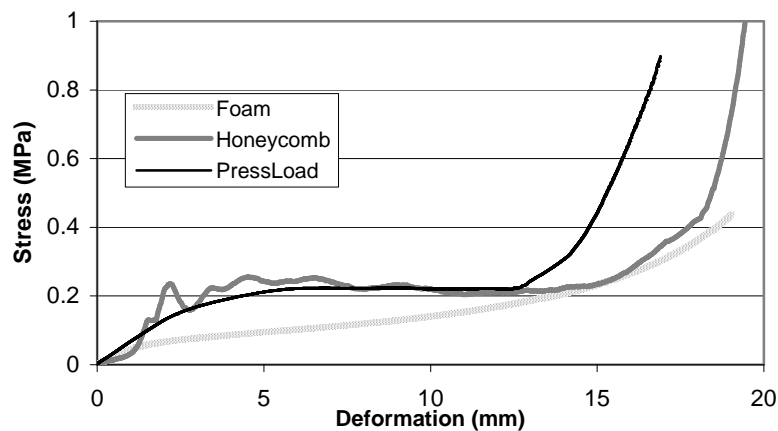


**Fig 3: After testing (just before densification)**

- The parameters adjusting the stress level are:
  - Material
  - Wall thickness
  - Shape
  - Density of cones
- A skin could be used in order to obtain a better mechanical homogeneity in the compression direction.
- A sandwich structure allows better angular properties (cell fixation).

## 4. EXPERIMENTAL WORK

### 4.1 Static test



*Graph 2: Comparison between absorbers*

Graph 2 shows the static characteristic for a typical PressLoad absorber. The main features of the graph are:

- No initial peak
- Flat plateau
- 65% energy absorption

Also shown on graph 2 are typical characteristics for foam and precrushed honeycomb. The graph clearly shows that PressLoad compares well with precrushed honeycomb in this test. Both show a significantly better crush characteristic when compared with the PU foam.

### 4.2 Dynamic test

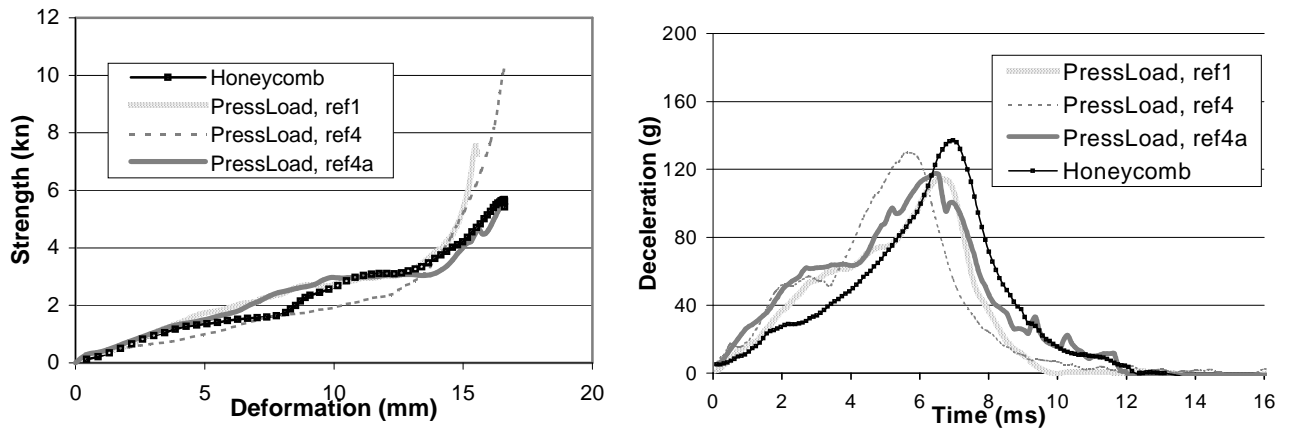
Dynamic tests were carried out using a dome head impactor at 4.2 m/s. The results for the various PressLoad samples compare well with results for aluminium honeycomb. The results are shown in graphs 3 & 4, and in table 1.

Reference	Description	HIC value*
PressLoad Grade 1	Aluminium / 1 skin	390 ± 50
PressLoad Grade 4	Polycarbonate / none	650 ± 50
PressLoad Grade 4 a	Polycarbonate / 1 skin	400 ± 50
Honeycomb structure	Aluminium	420 ± 50

*Table 1: Dynamic characteristics*

\*HIC value (Head Injury Criteria) has been calculated using equation 1:

$$\text{HIC} = \left( \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a dt \right)^{2.5} (t_2 - t_1) \quad (\text{Eq 1})$$

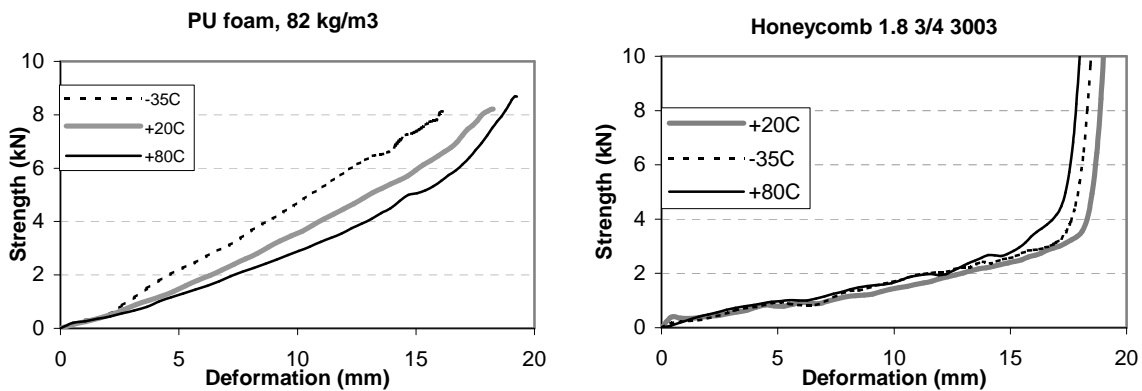


Graphs 3 & 4: Comparison between absorbers and PressLoad references

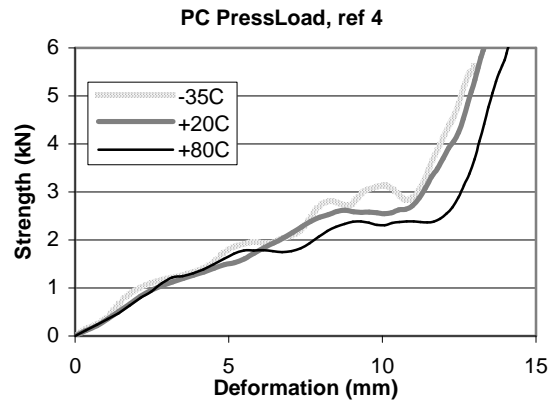
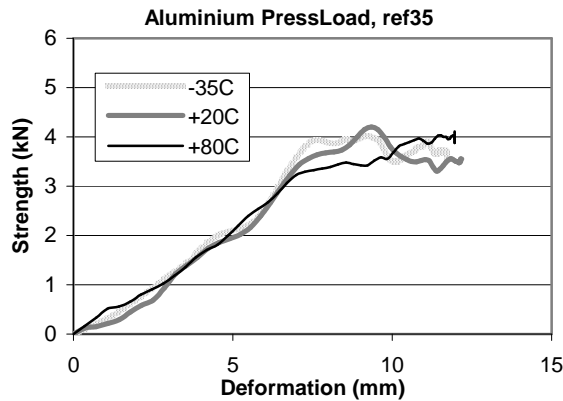
### 4.3 Thermal properties

(Dynamic test: dome head, 4.5 kg, 4 m/s)

The following graphs (5 - 8) show how the strength of various absorbers varies with temperature. Typical aluminium honeycomb absorbers show a stable characteristic, and PU foam is quasi-stable with about  $\pm 15\%$  variation between  $-35\text{ }^\circ\text{C}$  and  $+80\text{ }^\circ\text{C}$ . The results below show characteristics for aluminium and polycarbonate PressLoad parts. The aluminium PressLoad shows a stable characteristic, as would be expected for a metal part. A high thermal, high impact polycarbonate was chosen for the parts in these tests. The results show stable behaviour between  $-35\text{ }^\circ\text{C}$  and  $+80\text{ }^\circ\text{C}$ .



Graphs 5 & 6: Temperature influence for PU foam and Honeycomb ( $-35\text{ }^\circ\text{C}$  to  $80\text{ }^\circ\text{C}$ )



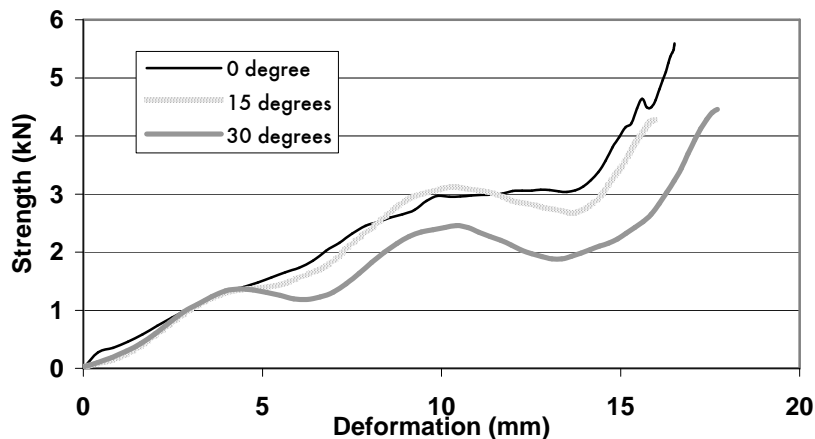
Graphs 7 & 8: Temperature influence for aluminium PressLoad and PC PressLoad (-35 °C to 80 °C)

Through careful material choice (metals or high thermal, high impact thermoplastics) it is possible to produce PressLoad structures that are thermally stable.

#### 4.4 Oblique impact tests

The angular properties of PressLoad will be discussed briefly. Tests were performed at 0°, 15° and 30° from vertical. The parts tested consisted of a flat PressLoad with a single 1 mm skin. Experimental results are shown in graph 9.

The results show that there is little difference between results at 0° and 15°. The result for the 30° impact shows double plateau behaviour.



Graph 9: Single layer core + 1 mm skin

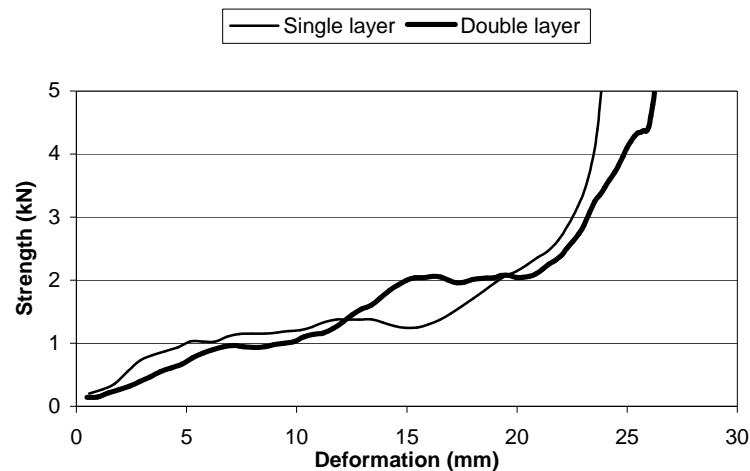
Angle °	HIC value
0	400 ± 50
15	330 ± 50
30	290 ± 50

Table 2: HIC Values for Oblique impacts

Tests were carried out at 0°, 15° and 30°. Beyond 30° the collapse mechanism of the PressLoad cones becomes unstable. As the angle increases the effective crush depth also increases. This increase in crush depth gives a corresponding reduction in the HIC value as shown by the results in table 2.

## 5. SANDWICH STRUCTURES

Multi-layer PressLoad structures are easily achieved by joining the flat tops of the cones. The static characteristics of these structures have been investigated and the results are shown in graph 10. The double layer structure shows a double plateau due to a two stage crushing mechanism. The first layer crushes to give the first plateau, and this crushed layer then acts as a skin during the second stage. Further investigations are being carried out regarding the multi-layer structure for improvement of angle impact behaviour and improvement of flexural and torsional stiffness.



*Graph 10: Comparison between a single and a double layer absorber*

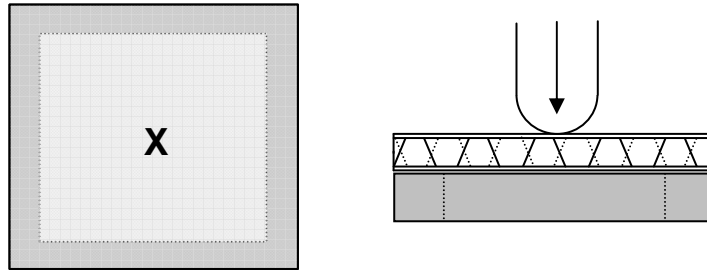
Structural members made up of two stiff, strong skins separated by a lightweight core are known as sandwich panels. The separation of the skins by a structure such as PressLoad increases the moment of inertia of the panel with little increase in weight. This results in a structure that is light, but also resistant to bending and buckling loads.

The mechanical properties (angular impact performances, flexural and torsional strength) can be optimised by the addition of skins (either one or both sides), the design of a multi-layer structure or by the incorporation of a soft material inside the structure. This addition of new structures (skins, or additional layers) creates some new energy absorption modes, without changing the excellent impact characteristics.

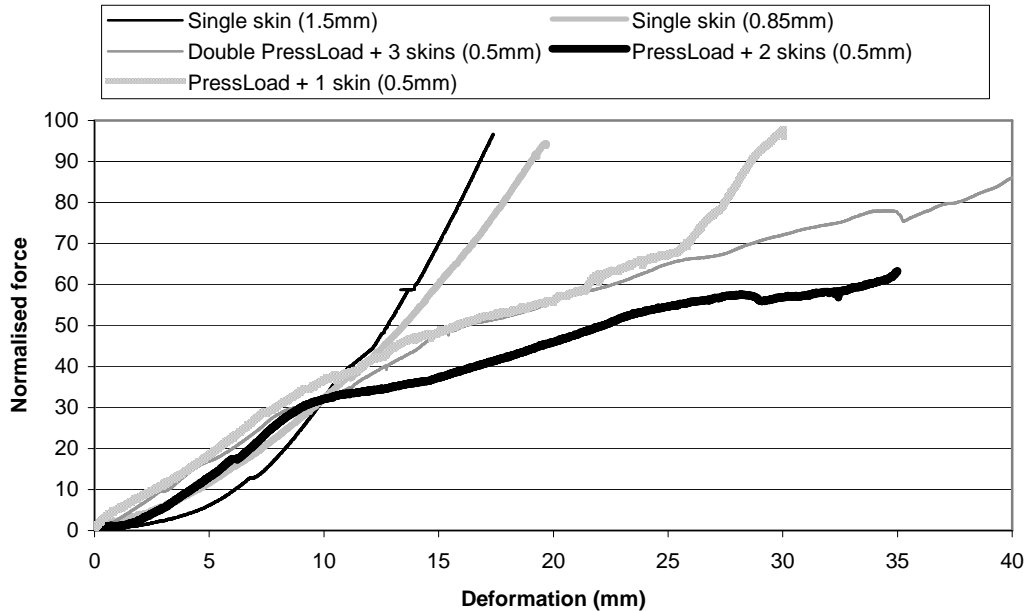
The mechanical behaviour of sandwich panels depends on the properties of the face and core materials and on its geometry. For most applications a panel is required to have some minimum stiffness for a specified maximum loading. The panel should also be as light as possible. The design of a sandwich panel can therefore be seen as an optimisation problem, where the structure must meet constraints on strength and stiffness while keeping its weight to a minimum. The design can be optimised by altering the core and skin thickness, core and skin materials, and the properties of the core itself.

### 5.1 Bending tests

A number of tests were performed to determine the behaviour of materials when loaded as shown in figure 4. The edges of the sheet or panel were fully supported and the loading was applied at the central point. This represents how a head might impact a bonnet structure. Normalised results for various sheet materials and PressLoad sandwich panels are shown in graph 11.



**Fig 4: Bending test set-up**



**Graph 11: Bending properties**

The sheet materials show a rapidly increasing force over the duration of the test. The sandwich structures however show increase with a more gentle gradient. This would indicate lower peak forces, for example, in an impact situation.

## 6. APPLICATIONS AND FUTURE WORK

PressLoad has many applications in vehicle safety. Specially shaped absorbers can be designed for interior protection. Panels can also be used for floor and boot applications. There is also great scope for use in bonnet and bumper applications for pedestrian protection. The development of PressLoad for these applications is ongoing. A few of the areas of interest are detailed below.

- Development of new geometries
- Influence of the wall thickness (continuum, gradient)
- Relation between geometry (angle, height, diameter of the cone, number of cells) and mechanical properties, study with simulation tool (LS-Dyna)
- Study of sandwich structure
- Oblique impact (single layer, sandwich, with skin(s))
- Influence of holes or other cuts in the structure
- Further research into bending structures for bonnet applications

## CONCLUSIONS

In comparison to the classical energy absorbers, the PressLoad structure has many advantages:

- Energy absorption capacities: 65% plateau
- Excellent Stress/Weight ratio
- Angular energy absorption (especially for sandwich structures)
- Adaptable acoustic properties
- Exceptional flexural stiffness when sandwiched
- Excellent mechanical stability at very low stress level (compression)
- Easy to produce: Cold forming, thermoforming or injection moulding
- Available in many materials
- Cost effective solution
- Continuous structure: Waterproof, can be used as a membrane
- Recyclable and safe
- Many possibilities in automotive applications