

# **Pedestrian protection potential of an adaptive bumper**

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## **ABSTRACT**

Cellbond Composites Ltd. is currently working on a new front bumper design, which meets the conflicting requirements for pedestrian protection and low speed collisions.

For speeds below 5 mph, the bumper stiffness should be high, while for higher speeds the bumper must have a low stiffness and good energy absorption characteristics. Monitoring vehicle speed so the bumper stiffness can be adapted accordingly is the key principle behind this concept.

The innovative element of this adaptive system concerns the anisotropic material (e.g. honeycomb) situated behind the bumpers front face. By rotating this component through a range of angles, a number of stiffness levels can be realised.

## **1.0 INTRODUCTION**

### **1.1 Background**

Throughout 1999, in the European Union, approximately 42,000 people died and another 1.3 million were injured due to road traffic accidents. Almost 20% of these traffic related fatalities involved either pedestrians (6,000) or cyclists (2,300) (1).

In Britain, pedestrian impacts account for over 900 deaths and some 40,000 casualties each year (2). Statistics such as these prompted the Government to publish new casualty reduction targets, with the aim that they should be achieved before the start of the next decade (3).

- 40% for all road deaths and serious injuries
- 50% for child road deaths and serious injuries
- 10% for the rate (by vehicle kilometers) of slight injuries

Many of the other EU members are aiming for similar reductions. To achieve such targets, the European Experimental Vehicles Committee (EEVC) has recommended a number of 'test methods to evaluate pedestrian protection afforded by passenger cars' (4). Although principally the same, ACEA ([www.acea.be](http://www.acea.be)) and the ISO have their own proposals on what form such an evaluation should take. All three suggestions include the requirements for evaluating a car's bumper system.

A large percentage of pedestrians injured sustained lower leg or knee injuries. Although not life threatening, such injuries can be extremely serious, often resulting in long term or permanent disability. It is widely accepted that a vehicle's leg impact performance is heavily influenced by the bumper system used (5).

This paper sets out to explore the 'pedestrian protection' potential of an adaptive bumper, i.e. a system that monitors vehicle speed and alters the bumper stiffness accordingly.

## **2.0 OUTLINE OF TEST PROCEDURES**

### **2.1 Pedestrian impact**

To replicate a typical pedestrian impact event, the European Experimental Vehicles Committee (EEVC WG 10/17) has developed a test procedure (4), which is both repeatable and accurate. It is inevitable that, in the near future, the European Commission (EC) will introduce legislation based on these requirements. Already, such a method is used for many of the tests that Euro NCAP ([www.euroncap.com](http://www.euroncap.com)) conducts.

To represent a pedestrian accident at 40km/h, the EEVC proposes the use of four sub-system tests:

- Child head-form to bonnet tests
- Adult head-form to bonnet tests
- Upper leg to bonnet leading edge tests
- Lower leg to bumper tests

Because this concept aims to reduce pedestrian lower leg injuries, only the last procedure on the above list is relevant. For this particular test, a leg-form impactor is propelled towards the car front with an impact velocity of 40km/h (11.1m/s). A minimum of three tests must be performed,

one each to the middle and outer thirds of the bumper. The acceptance levels that have been proposed for this test are as follows:

- Maximum lateral knee bending angle should be less than or equal to 15.0°
- Maximum lateral knee shearing displacement should be less than or equal to 6.0mm
- Maximum lateral tibia acceleration should be less than or equal to 150g

## **2.2 ECE approval of vehicles with regard to their front and rear bumpers**

Regulation Number 42, from The United Nations Economic Commission for Europe (ECE), states that, a car's safety systems must continue to function correctly after the vehicle has been impacted with either a pendulum or a moving barrier. The car should be struck at a velocity of 4km/h (approximately 2.5mph) across the full width, and 2.5km/h (approximately 1.5mph) on the corners, this procedure must be performed on both the front and rear bumpers. The tests must be carried out at a height of 455mm above ground level, under loaded and unloaded conditions (6).

## **2.3 Insurance tests**

To determine insurance ratings, passenger cars are tested with a rigid barrier. For frontal tests, the barrier is fixed and the vehicle moves, the exact opposite is true for tests to the rear. This procedure is conducted at a velocity of 15km/h with a 40% overlap (7).

After the test, trained engineers determine the cost of returning the vehicle to its pre-accident condition. Equipped with these figures, insurance companies can then define the damage classification of the car type.

One year after the first vehicles have been delivered, the damage classification is re-assessed based on data obtained from real-life accidents.

FMVSS 581 specifies the American requirements for low-speed collisions, while CMVSS 215 is the equivalent Canadian regulation.

## **2.4 High speed crash**

To check that a car will offer adequate protection to its occupants in the event of a frontal collision, tests are carried against an offset deformable barrier. The European directive (8) states that the impact velocity should be 56km/h. For vehicles to pass such a test, measurements taken from dummies must satisfy a number of pre-defined requirements. Euro NCAP tests vehicles' using a similar set-up but the impact speed is increased to 64km/h, and the biomechanical criteria are more severe (9).

## **3.0 THE NECESSITY OF AN ADAPTIVE STRUCTURE**

The various test procedures outlined in the previous section have conflicting requirements. For pedestrian protection purposes, the bumper stiffness should be low to allow efficient energy absorption. However, to maximise damage protection in the event of a low speed collision (up to 15km/h), the bumper stiffness needs to be a lot higher. Currently, manufacturers tend to

concentrate on minimising impact damage; as a result, pedestrian protection tends to be overlooked. To satisfy the diverse impact requirements, it seems that future bumper systems will need to be adaptive.

#### **4.0 CONCEPT IDEAS FOR ADAPTABLE BUMPER STIFFNESS**

There are a number of possible methods for creating a bumper system with adjustable stiffness.

The first comprises of a solid member, which is positioned against the bumpers leading surface. It is held in place from behind via a number of cylinders, which are made from two parts so that one half can move inside the other. For low speeds (below 5mph), the cylinders are locked at their maximum length, which can be done using a number of methods including, solenoids, electro-magnets, friction blocks and hydraulics; this makes the bumper extremely stiff, ideal for damage limitation. For higher speeds, the locking mechanism is released, so that in the event of a pedestrian impact the cylinders are free to reduce in length (by a maximum of 50%). This allows the front member to move backwards, which in turn crushes an energy absorbing material behind. There are a number of possible materials (and strengths) for the energy-absorbing element; it is just a case of selecting the best option.

Another concept consists of a pressure chamber for containing fluid (e.g. air), which is positioned adjacent to the bumpers front face. This compartment has an outlet, through which the fluid flow can be regulated, and an inlet, to which a pump is connected. By using the pump to pressurise the chamber the bumper becomes rigid, increasing the bumpers deformation resistance. At speeds above a certain threshold (Probably 15km/h), to allow energy absorption, the chamber is depressurised using the controlled outlet. To have better control over the peak deceleration, during a pedestrian impact, it may be necessary to incorporate a PressLoad (patented energy absorber, Cellbond Composites Ltd.) structure.

This final system uses either honeycomb, or an array of cylindrical tubes, housed within a conventional bumper skin. The key property of these two materials is that their stiffness is significantly higher in one direction (along the cell axis) than it is in the other, i.e. they are anisotropic. Therefore, by rotating such a material the bumper stiffness can be adjusted to the vehicle's speed. This rotational movement would be performed by some form of mechanical mechanism.

#### **5.0 OVERVIEW OF THE COMPLETE BUMPER SYSTEM**

Although only a very simple representation, figure 1 shows how an adaptive bumper system would be positioned within a car.

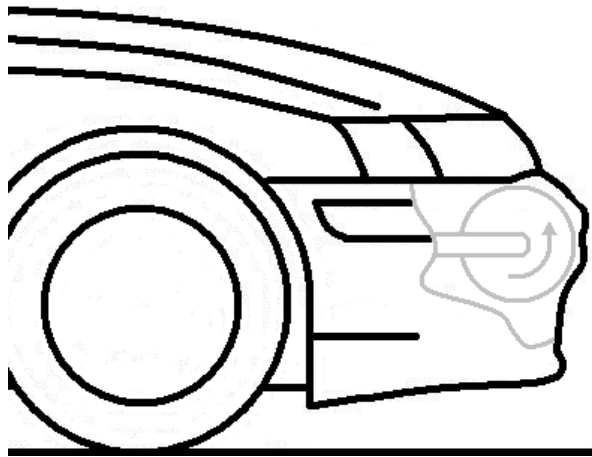


Figure 1. The positioning of the adaptive bumper system

## 6.0 EXPERIMENTAL WORK

### 6.1 Aims of experimental work

As mentioned previously, a number of materials/structures possess anisotropic behaviour, honeycomb is an obvious example. To obtain relevant data, for this adaptive system, two series of static tests were conducted on such a material

#### 6.1.1 Cubic samples – series A

To keep things simple, the first set of tests involved looking at the crush strength of expanded honeycomb cubes, when loaded (perpendicular to the face) from different directions.

#### 6.1.2 Semi-circular samples – series B

To reduce the complexity of the mechanism needed for rotation, it is highly likely that this concept's energy-absorbing element will be circular. However, it was decided that for the purpose of this study the samples should be semi-circular in cross-section to eliminate unpredictable slippage.

## 6.2 Sample specifications

### 6.2.1 Cubic samples – series A

The samples were cut from the same variety of honeycomb, which is typically identified by the reference, 1.8 – 3/4 – 3003. The first part of this code shows the density in pounds per cubic foot, the second part is the cell size in fractions of an inch and the final part represents the aluminium alloy used.

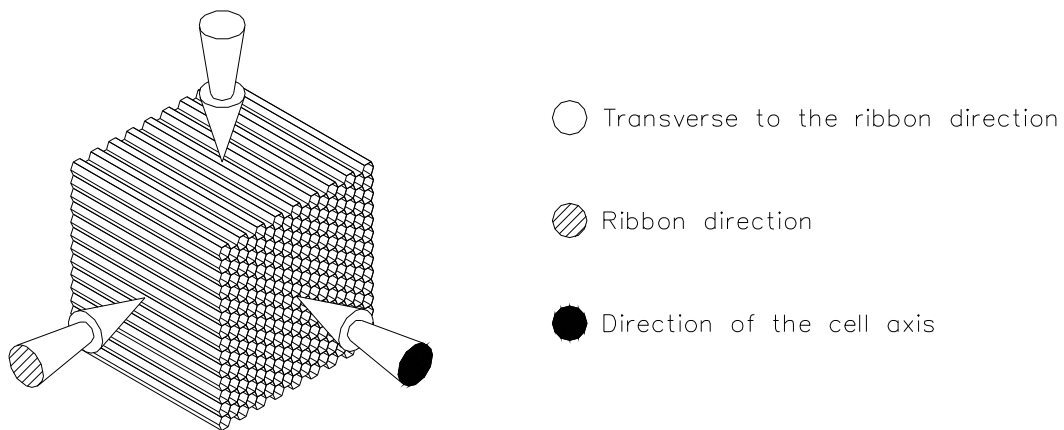


Figure 2. Sample details

Geometric details: Length – 250mm (ribbon direction)  
 Width – 250mm (transverse to the ribbon direction)  
 Height – 250mm (direction of the cell axis)

### 6.2.2 Semi-circular-samples – series B

The material used for the first set of samples, 1.8 – 3/4 – 3003 honeycomb, was also used for the second. To replicate a honeycomb tube being loaded from different directions, these semi-circular samples were cut with a range of cell orientations (0 to 90 degrees, figure 3).

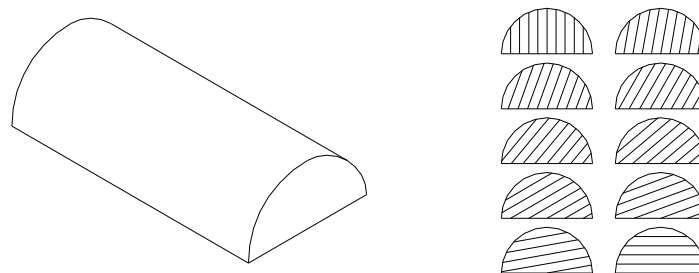


Figure 3. Sample details

Geometric details: Length – 200mm (expanded direction)  
 Height – 50mm  
 Width (diameter) – 100mm

## 6.3 Test procedures

### 6.3.1 Cubic samples – series A

The tests on the cubic samples were performed with a Lloyds LR 150 K static test machine, using a compression speed of 100mm/min.

The samples were compressed, between two parallel platens, in one of three possible directions, x, y or z (please see figure 2). To check repeatability, several tests were conducted for each

loading condition. For tests in the direction of the cell axis, to initiate failure, it was necessary to peen the honeycomb. No pretest adjustments were needed for the remaining samples.

### 6.3.2 Semi-circular samples – series B

To achieve better resolution, this round of tests was performed with a Lloyds LR 50 K static test machine, using a compression speed of 50mm/min.

Ten different cell orientations were tested, ranging from 0 to 90 degrees. Once again, to check repeatability, each sample type was tested three times. To hold the samples in place for the duration of the tests, sand paper was fixed to the top and bottom platens.

## 7.0 RESULTS

### 7.1 Analysis of results

The data acquired from the static tests is depicted in figures 4 through to 7. Due to the good repeatability it was deemed unnecessary to include the results for every sample tested.

#### 7.1.1 Cubic samples – series A

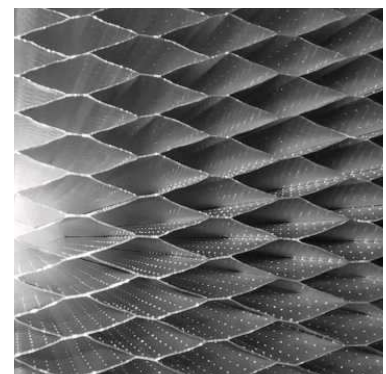
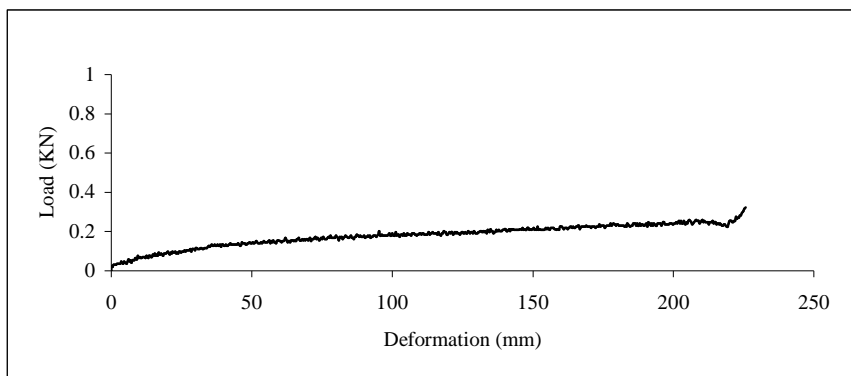


Figure 4. Honeycomb crushed transverse to the ribbon direction

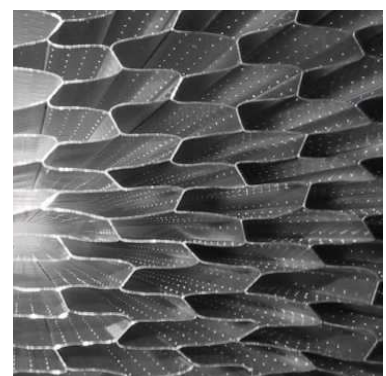
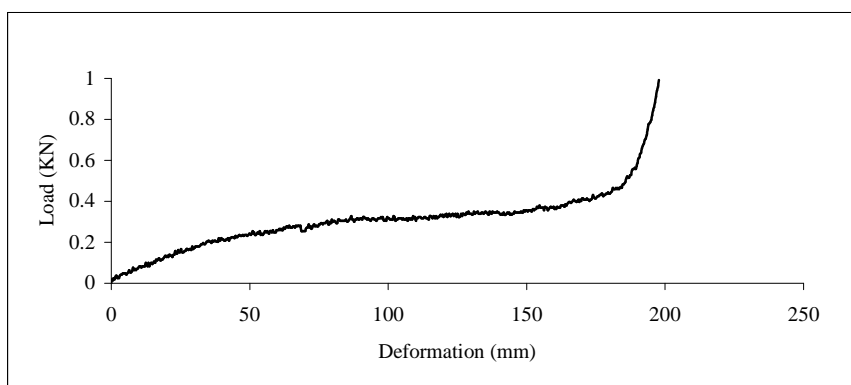


Figure 5. Honeycomb crushed in the ribbon direction

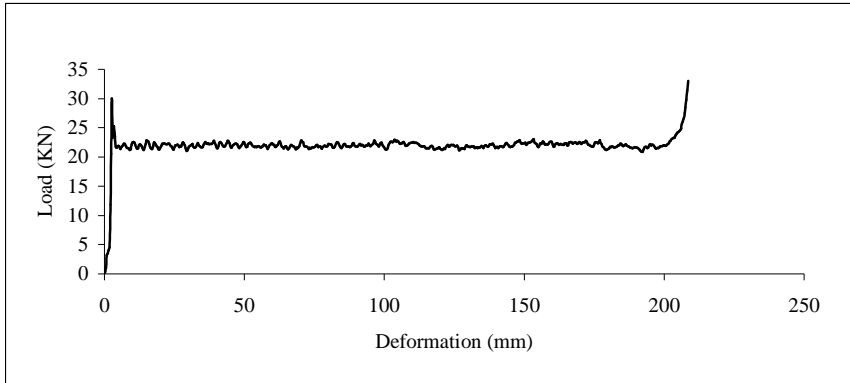


Figure 6. Honeycomb crushed in the direction of the cell axis

**7.1.2 Semi-circular samples – series B**

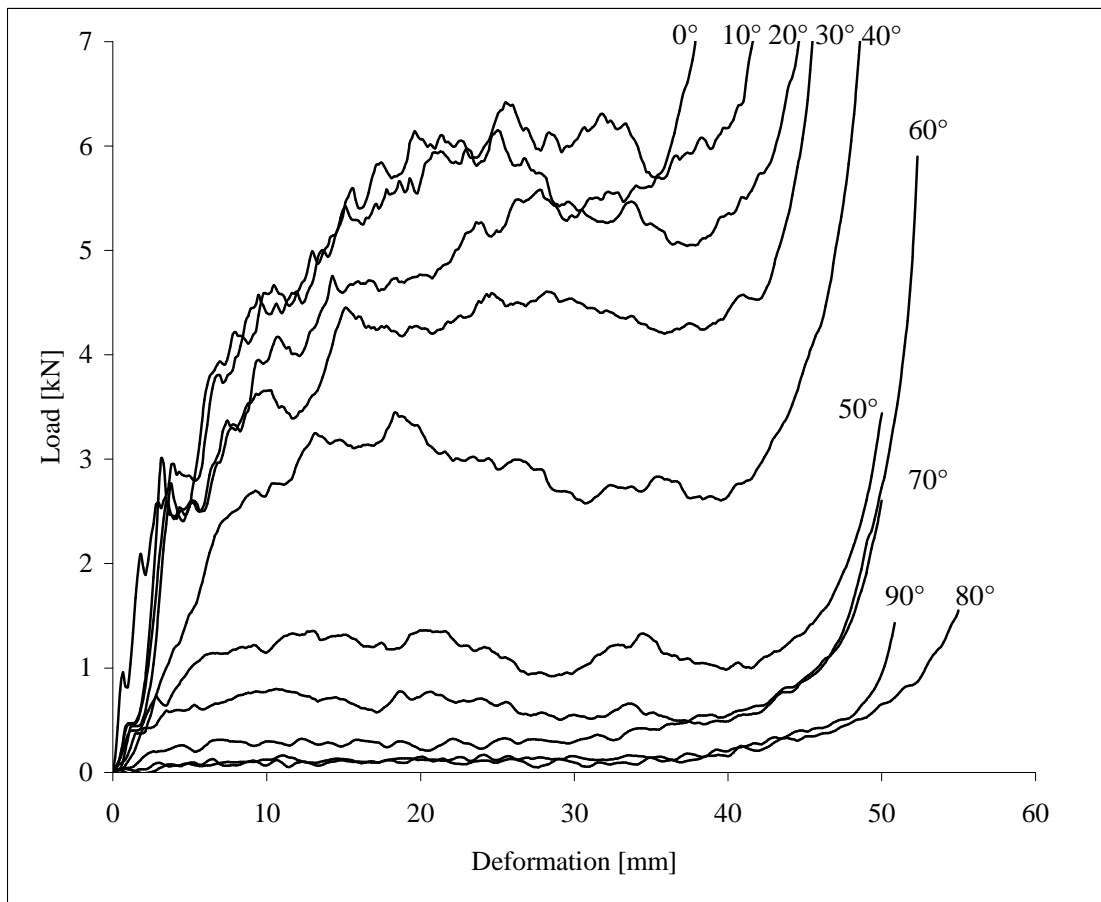


Figure 7. Semi-circular honeycomb samples with a range of cell orientations

## 8.0 DISCUSSION

### 8.1 Cubic samples – series A

Figures 4, 5 and 6 clearly illustrate the anisotropic behaviour of honeycomb. As expected, the crush strength is highest, in the direction of the cell axis.

The crush strength in the ribbon direction was approximately twice that of the expanded direction. There are two reasons for this; the first concerns the change in cell orientation, which alters the mechanism of deformation. Secondly, the way honeycomb is produced means that two of the six cell walls are twice the thickness of the rest, which significantly increases the crush strength for samples loaded in the ribbon direction.

When compressed in the ribbon direction, the cell walls initially bend, which results in linear-elastic deformation. Next, once a critical stress is reached, plastic yielding causes the cells to collapse. Finally, opposing cell walls touch one another and the stiffness level rises sharply, this stage is known as *densification* (see figure 5).

The mechanism of deformation for aluminium honeycomb, when compressed in a direction transverse to the ribbon, is straightforward. What happens is that the honeycomb simply returns to its pre-expanded state, with little or no bending of the cell walls (see figure 4).

### 8.2 Semi-circular samples – series B

For reasons explained earlier, if a honeycomb is compressed in-plane as opposed to along the cell axis, the crush strength is considerably lower.

The idea behind this second test series was that, by rotating the core between 0 and 90 degrees, it should be possible to obtain a range of crush strengths between the maximum and minimum values. A quick look at figure 7 confirms this theory.

When simplified, the deformation behaviour of all ten samples can be classified into one of three groups. Samples with a cell orientation of less than 30° yielded plastically (typical behavior for aluminium honeycomb) in the direction of the cell axis. By plotting pressure against deformation, the stress levels were found to be virtually constant, which illustrates further the crush mode over this range. Although minimal, some collapse occurred, which accounts for the crush strength variations. When samples with a cell orientation of 66° or greater were compressed, the honeycomb simply folded in the ribbon direction i.e. the non-expanded direction. Figure 6 shows the low load required to do this, it is also worth noting the constant crush strength, which is critical for efficient energy absorption. Between 30° and 66°, due to the transition between different forms of deformation, the load levels changed dramatically (this is especially true for cell orientations between 30° and 51°). In this final group, deformation is a complex mixture of plastic yielding in the cell direction, buckling of the cell walls, and folding in the ribbon direction.

## 9.0 FUTURE WORK

The aim of this paper was to introduce the adaptive bumper concept and not to provide a fully developed solution; therefore, there is still a lot of work to be done. Initially, further studies will be necessary to find an effective, commercially viable anisotropic material/structure for the systems energy-absorbing element. Once this has been achieved then the many issues concerning real world implementation will need to be addressed, such as the mechanics required for rotation.

## 10.0 CONCLUSIONS

This paper has demonstrated that an adaptive bumper, based on an anisotropic material, could contribute significantly to the 'pedestrian friendliness' of a vehicle's front end, while retaining high levels of durability. However, before such a concept is ready for full size trials, development of the necessary mechanics is required.

## 11.0 REFERENCES

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