The main purpose of an impact attenuator is to progressively dissipate the kinetical energy given by an obstacle during a frontal crash. It is the first structural component giving reaction and safety performance as soon as a car accident occurs, that's why its engineering design is very important: the deceleration given to the driver during an impact may have mortal consequences and it's necessary to keep them the lowest and the most progressive as possible.

Formula SAE 2010 rules give strict requirements on two data measurements during the impact: the peak deceleration must be lower than 40g and second the average deceleration must be lower than 20g.

In order to guarantee its driver's safety, Dynamis PRC has developed an impact attenuator made of aluminum honeycomb structure and aluminum plates.

Here follows a sum of the main information given by the maker of the material used:

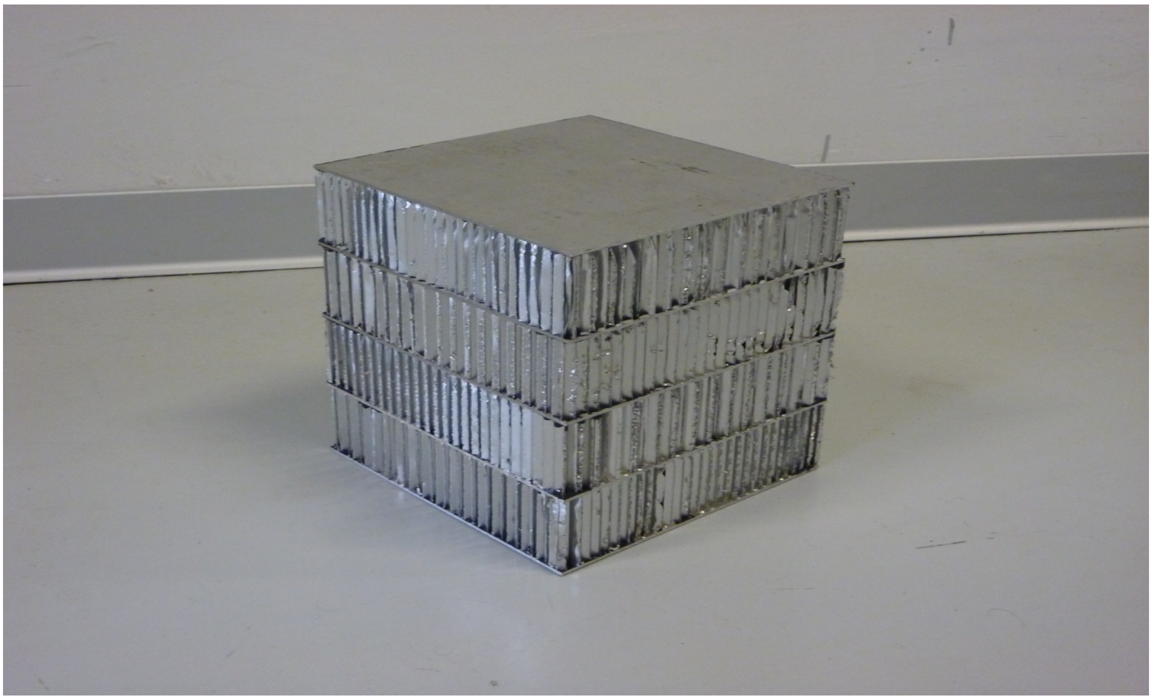
Material: Aluminum Honeycomb Sandwich Panel
Supplier: AVIOMETAL Spa, Via Sempione, 15
21011 Casorate Sempione (VA)
ITALY

Aluminum Type	3003
Density $[Kg/m^3]$	120
Cell Size [inch]	0.25
Thickness [μm]	50
Bare Compressive Strength [Mpa]	2.1

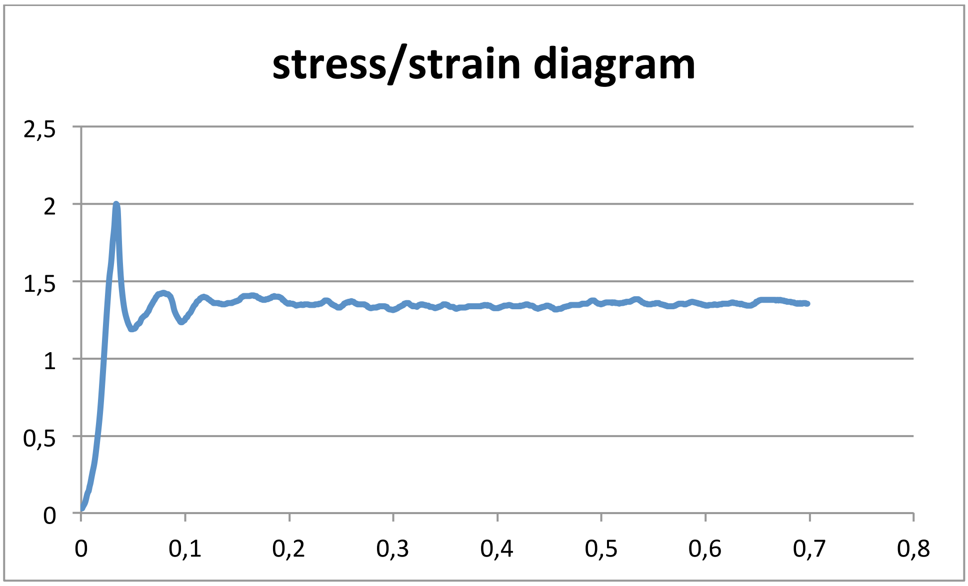
The impact attenuator is built by 4 layers of sandwich panels each one made by one honeycomb and 2 aluminum panels. The sizes of the component are:

Honeycomb panel thickness [mm]	50
Honeycomb panel width [mm]	200
Honeycomb panel height [mm]	200
Honeycomb panel area [mm²]	40000
Number of panels	4
Aluminum plate thickness [mm]	2
Number of aluminum plate	5
Total thickness of Impact Attenuator [mm]	210

Here's a picture of the Impact attenuator before crashing



Since the supplier couldn't provide us the compressive yield stress, we managed to verify the typical mechanical behavior of honeycomb panels and the compressive yield stress by testing our component on a press machine:



The main features of the diagram are the linear stress-strain elastic behavior and the flat stress-strain plastic behavior; during the plastic behavior, the material shows the typical buckling effects. The elastic behavior is responsible of the peak deceleration of the mass at the beginning of compression of any honeycomb layer: in order to start the buckling behavior, the force given by the mass to the component reaches the value able to yield the honeycomb.

The value of compression yield strength found on the quasistatic compression is equivalent to 2 MPa.

Since we couldn't forecast the strain-rate behavior of the material used, we decided to use the data obtained through the quasi-static compression, because the velocity of impact isn't high and the stress-strain behavior may be very similar at this speed too.

By sizing the resistant area of the layers, the maximum force developed to yield the material changes:

$$F_{yield} = \sigma_{yield} \cdot A_{res}$$

The same force gives the peak deceleration to the mass. The rule restricts the deceleration to 40 g, so the force is

$$F_{yield} = m \cdot 40 \cdot g = 300 \ \cdot 40 \ \cdot 9.81 = 117720 \, N$$

So the maximum resistant area that yields at 117720 N is

$$A_{res} = \frac{F_{yield}}{\sigma_{yield}} = \frac{117720}{2600000} 0{,}04519 \, m^2$$

That is given by a squared area of 212 mm side. In order to be safe and comply with SAE rule, we decided to size the side to 200 mm.

The average deceleration can be easily found out through the kinetical energy – force work equation, on the hypothesis that the force is constant during all the impact and at its maximum value according to the rules:

$$E_k = F \cdot \Delta s \qquad \text{and} \qquad F = 20 \cdot g \cdot m = 20 \cdot 300 \cdot 9.81 = 58860\ N$$

E_k is equal to $\frac{1}{2} \cdot m \cdot V^2 = 7350\ J$ so the displacement of component's thickness on the maximum average deceleration possible according to the rule is

$$\Delta s = \frac{E_k}{F} = \frac{7350}{58860} = 0{,}1248\ m$$

In reason to offer enough displacement, the component has to be thicker 1.5 times, because it isn't possible to compact its entire thickness

$$\Delta s_{real} = \Delta s \cdot 1.5 = 0.1872\ m$$

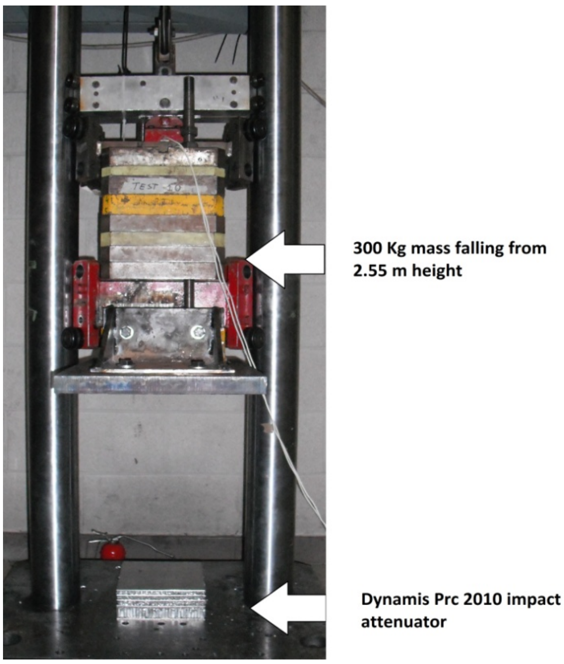
In order to mount a safe impact attenuator, it's been decided to get 0,2 m thickness, made by building up 4 sandwich honeycomb panels one over the other, bonded all together using 3M DP 190 epoxy adhesive.

After the general sizing design, a dynamic test of the impact attenuator was carried out. The test was carefully conducted in a controlled environment to ensure its reliability at LAST (Laboratorio di Sicurezza dei Trasporti) inside the aeronautical engineering department of Politecnico di Milano.

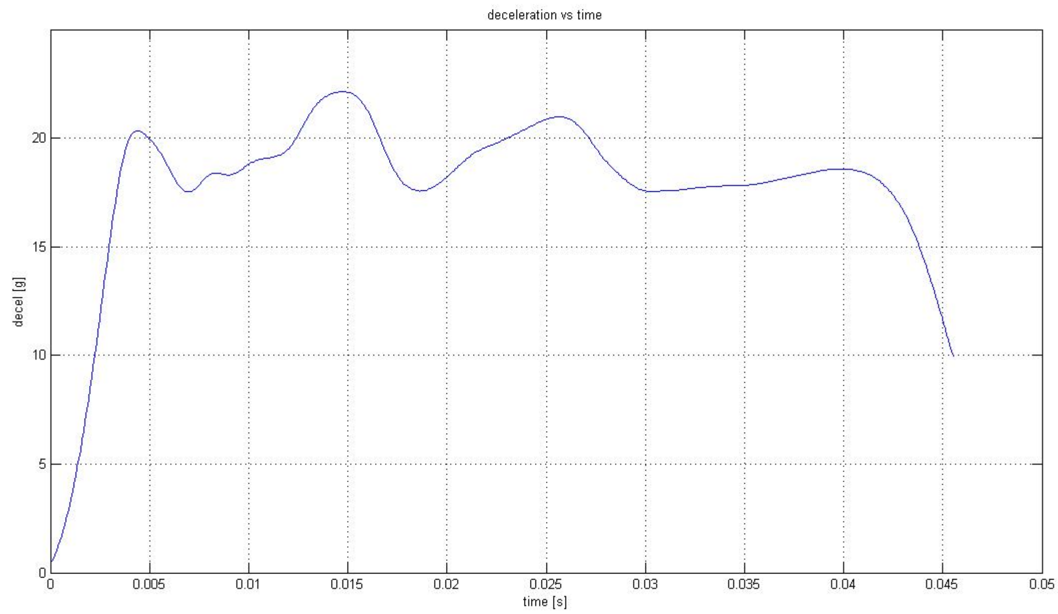
To simulate an actual crash (as laid out in section 3.21 of the rules), the attenuator, loaded with ballast weight, was dropped from a height of 2,55 m onto a non-yielding floor surface with a built-in load cell. The height of impact was calculated by equating it final kinetic energy immediately before impact to the structure's initial potential energy

$$\frac{1}{2} \cdot m \cdot V^2 = m \cdot g \cdot h$$

The 300 Kg mass has been loaded with 2 ENTRAN acceleration sensors, using 16 channels 100 KHz Pacific Instrumentation data capture system, a high frames per second camera has been used for collecting a video of the impact. The raw data have been filtered with a Channel Filter Class (CFC) 60 (100 Hz) filter per SAE Recommended Practice J211. Here's the machine used to simulate the crash



The resulting deceleration on the 300 Kg mass have been plotted on matlab.



It's clear that according to specification data the impact attenuator is complying with section 3.21 of FSAE rules: the peak decelerations are maximum equivalent to 23g and all the peaks are similar, this means that any of them represent the dynamic yield stress of every honeycomb sandwich panel. The last peak is lower than the others and that is given to the fact that the last honeycomb panel that collapses has already been charged by all the history of the impact and it is closer to its dynamic yield stress.

Data elaboration on Matlab has also given the average deceleration value during the impact. Our impact attenuator obtains an average deceleration of 17.77 g, that complies with FSAE rule.

The total displacement of the whole impact attenuator on the impact is 130 mm, this means that the thickness of the impact attenuator is enough to adsorb the energy.