Adaptive crash energy absorber based on a granular jamming mechanism

Piotr Bartkowski*, Hubert Bukowiecki, Franciszek Gawiński, Robert Zalewski

Warsaw University of Technology Faculty of Automotive and Construction Machinery Engineering

Abstract. The following discussion concerns the use of innovative smart materials called vacuum-packed particles (VPP) as active energy absorbers. VPP, also known as a granular jamming system, is a structure composed of granular media contained within an elastomer coating. By changing the vacuum pressure inside the coating, it is possible to control the mechanical properties of the structure. VPP have many applications, e.g. in medicine, robotics and vibration damping. No attempts have yet been made to use VPP to absorb the energy of a collision, although given their properties, this could very well be an interesting application. In the first part of the paper, the general concept of the absorber is presented. Then a protype and the empirical tests conducted are precisely described. The middle part of the paper considers the basic properties of VPP and modeling methodology. A proposal for a constitutive equation is presented, and a numerical simulation using LS-Dyna was performed. In the final section, the concept of a smart parking post is presented.

1. Granular jamming mechanism

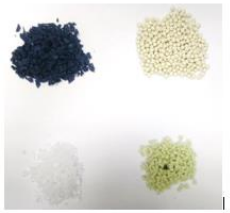

Fig.1. Some example of particles used in VPP (PC+ABS C1200H POM, ABS).

Fig.2. Beam made of VPP.

2. General concept of the absorber – design and tests

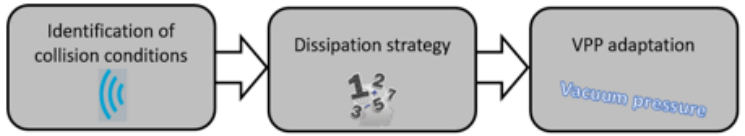

Fig.3. Block diagram.

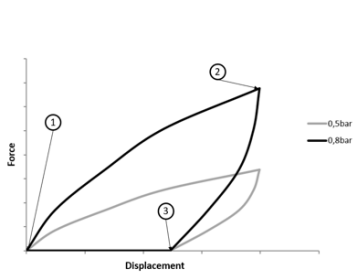

Fig.5. Conceptual absorber characteristic.

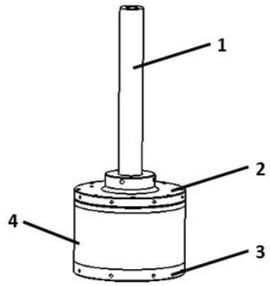

Fig.6. Basic absorber view.

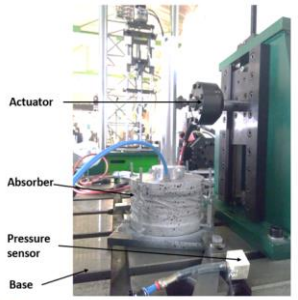

Fig.7. Test stand.

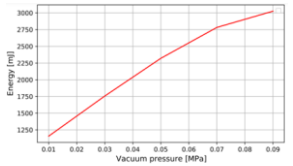

Fig.10. Energy in function of vacuum pressure.

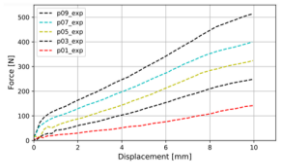

Fig.8. Force-displacement curve.

3. VPP modeling

$$\begin{cases} \Phi = \frac{1}{2} s_{ij} s_{ij} - \frac{\sigma_{y+/-}(\varepsilon, \dot{\varepsilon}, T, p)^2}{3} \leq 0 \\ \sigma_{y+/-}(\varepsilon, \dot{\varepsilon}, T, p) = \begin{cases} \sigma_{y+}(\varepsilon, \dot{\varepsilon}, T, p) & if\ I_\sigma > 0 \\ \sigma_{y-}(\varepsilon, \dot{\varepsilon}, T, p) & if\ I_\sigma < 0 \end{cases} \end{cases}$$

$$\sigma(\varepsilon, \dot{\varepsilon}, T, p) = (\alpha + \beta p + (\Psi + \gamma p)\varepsilon^{\Upsilon - \chi p})(1 + (\Xi - \mu p) \ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)),$$

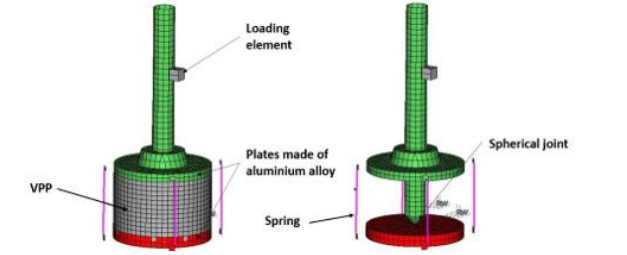

Fig.13. FE model.

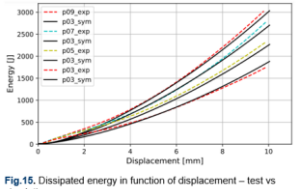

Fig.15. Dissipated energy in function of displacement – test vs simulations.

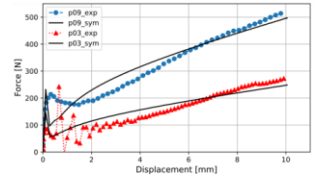

Fig.16. Force in function of displacement – test vs simulations.

3. Adaptive parking post

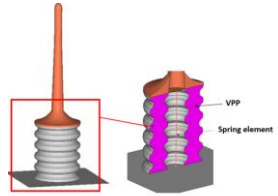

Fig.17. The concept of smart parking post.

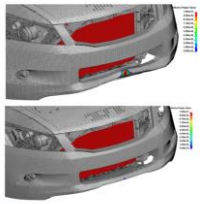

Fig.20. Equivalent plastic strain in car bumper ("stiff" parking upper, "soft" lower).

4. Conclusions

- By means of the vacuum pressure parameters, it is possible to control the dissipation of crash energy over a wide range using the granular jamming mechanism.
- VPP modeling using a modified Johnson-Cook model, called JC-p, makes it possible to predict the behavior of the material very well.
- A parking post could be a potentially attractive application of a smart absorber using the granular jamming mechanism, although further work is required.
- During the research work, some disadvantages of VPP structures were noticed that could limit the potential for being used in real objects, i.e. the low density of dissipated energy or limitations in the control speed of the device.

*e-mail: piotr.bartkowski@pw.edu.pl