CHALLENGE JOURNAL OF STRUCTURAL MECHANICS 2 (4) (2016) 212–215

Challenge Journal of Structural Mechanics

High strain rate and quasi-static compression behavior and energy absorption characteristic of PVC foam

Zhang Wei *, Ye Nan

Hypervelocity Impact Research Center, Harbin Institute of Technology, 150001 Harbin, PR China

ABSTRACT

The mechanical properties at room temperature of two densities PVC foams have been experimentally evaluated in both quasi-static and dynamic compression loading conditions. The strain rate effect have been evaluated by comparing the constant strength during plateau region. Energy absorption efficiency of PVC foam is investigated, and it shows that in certain density range, the efficiency of lighter PVC foam is larger than that of heavier PVC foam, but the efficiency stress of lighter PVC foam is smaller than that of heavier PVC foam. While the lighter PVC foam has been compressed more than heavier PVC foam when they reach their peak efficiency. Therefore, for a certain density of PVC foam itself, when the loading rates increase, the PVC foam will absorb more energy more efficiently.

ARTICLE INFO

Article history:
Received 13 September 2016
Accepted 11 November 2016

Keywords:
PVC foam
Mechanical properties
Strain rates effect
Energy absorption

1. Introduction

Foam materials have been extensively used in civil and military field such as energy absorbers to resist external loads (Zhu et al., 2010; Kabir et al.,2014). For example aluminum foam, it has already been widely investigated Deshpande and Fleck (2005); Lu et al. (2009). PVC, which stands for polyvinyl chloride, is a new type of structural functional materials, and it could be produced into PVC foam with high porosity, low density and low cost, which offers similar but higher performance ability of remaining a constant nominal stress in large plastic deformation than normal foam materials. And it is often used in Sandwich plates as core materials to make full use of advantages of the capability of dissipating considerable energy by large plastic deformation under static or dynamic loading. Avachat and Zhou (2015) investigate planar composites with PVC foam cores and E-glass/vinylester face sheets subjected to underwater shock. It is proposed that Low density PVC foams cores exhibiting better capabilities for compression than that of higher density cores. A major aim of this study is to provide a simple but reliable description of the compression behavior and energy absorption characteristic of PVC foams with the effect of strain rates of different densities.

2. Experimental Program

Density of polyvinyl chloride foam, short for PVC foam, is easily controllable, because of the porous property. While two different densities of PVC foams materials are considered in this test, which are 80 kg/m^3 (short for P80) and 160 kg/m^3 (short for P160). And each density of PVC foam specimens is cut into cylinder with nominal dimension of Φ30×10 mm from PVC foam layers with 10 mm thickness (Fig. 1).

Two densities of PVC foams specimens are compressed under quasi-static and dynamic loading, to determine their stress-strain relationship and strain-rate effect of them. Quasi-static tests are conducted on a micro-controlled electronic universal testing machine in room temperature. While PVC foams are compressed at constant given velocity between two steel plates. The given speeds are 1 mm/min and 100 mm/min in this test, which means that the strain rates were 0.167/s and 0.0016/s respectively.

Strain-rate effect is an important consideration to evaluate the mechanical characteristics of materials. And it is widely recognized as a crucial factor that influences the mechanical properties of materials. Because of the matrix material, entrapped air, as well as micro-inertia effect, foam material often exhibits very deep strain rate effect.

* *Corresponding author.* E-mail address: zhdawei@hit.edu.cn (Z. Wei)
ISSN: 2149-8024 / DOI: http://dx.doi.org/10.20528/cjsmec.2016.11.028

Therefore, accurate dynamic behavior is important in researching mechanical property of PVC foam. SHPB, which is short for split Hopkinson pressure bar, is a commonly used experimental technique to study constitutive laws of materials at high strain rates. In this test, a Φ40 mm split Hopkinson pressure bar is employed in the dynamic compressive tests for high strain rates. As shown in Fig. 2, strain gauges are glued on incident bar, transmitted bar as well as the Φ30×10 mm specimens. Dynamic tests were performed in room temperature till strain rate up to 3000/s.

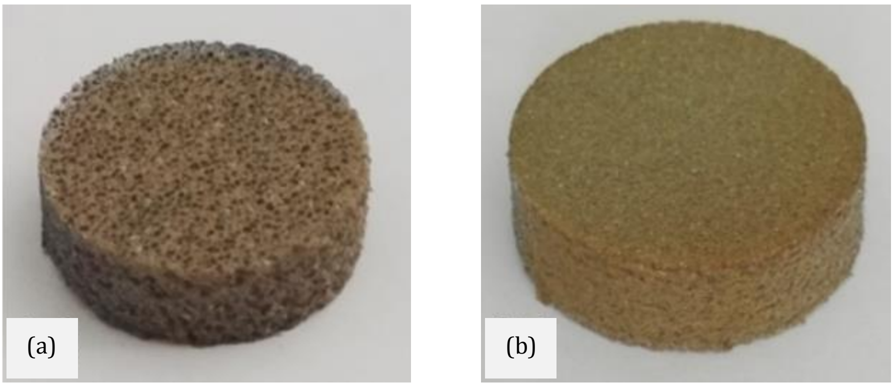

Fig. 1. Cylinder specimen (Φ30×10 mm) of the two densities PVC foams: (a) P80; (b) P160.

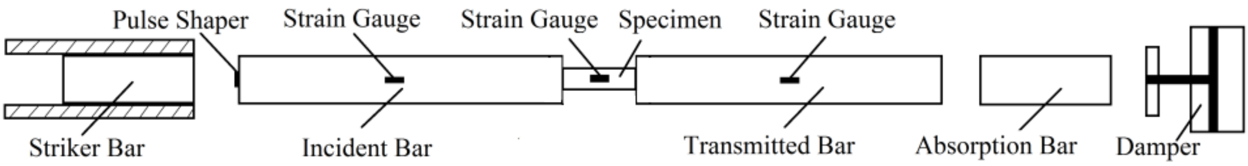

Fig. 2. Schematic of modified SHPB apparatus and specimen.

3. Results and Discussion

The ability of energy absorption and the accuracy of the finite element analyze are highly dependent on the accurate material parameters of PVC. In this test, uniaxial compression tests were performed at different strain rates in order to determine the sensitivity of the mechanical response to the loading rate. Fig. 3(a, b) shows the strain-stress curves of the two densities of PVC foams, 80 kg/m^3 and 160 kg/m^3 respectively, and it shows the strain rates effect between 10^{-3}/s and 3×10^3/s of the two densities of PVC foams. It has been indicated that the compression curves of PVC foams experience the typical deformation process of the metallic foams, and the strain-stress curves comprise of three apparently stages. At first it is elastic stage, the material and structure start to be compressed elastically, while in this stage a sharp linear increase in stress is observed with the strain increasing a little. Then it comes along with plateau stage, in which the stress keep almost stable or the slope of the curve is very small for a large range of strain, and the structure collapse occurred mostly in this stage, while the second stage is the main contributor to the large energy absorption capacity of foam materials. At last it is densification stage, and the cell wall itself have been pressed together, however it is seems that the stress increase exponentially.

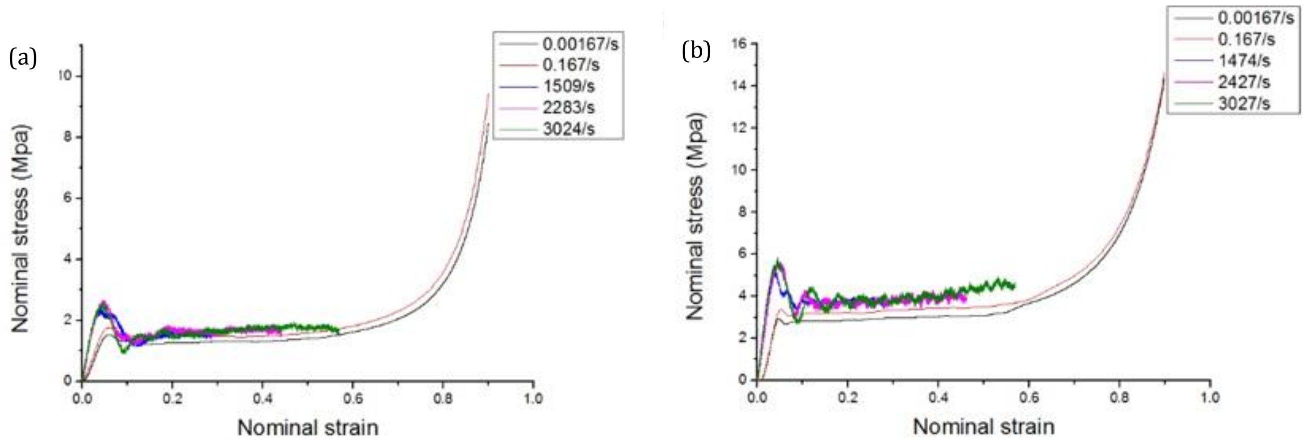

Fig. 3. Nominal strain-stress curve of the two relative densities of PVC foam: (a) P80; (b) P160.

Constant plateau stress in large plastic deformation is the most important factor of PVC foams in blast resistance. Table 1 shows the plateau stresses of the two densities of PVC foams under same or close strain rates. It is found that the plateau stresses increase with increasing strain rate in quasi static and dynamic compression conditions. And in quasi-static region, the plateau stress of strain rates 0.167/s of the two PVC foams increase nearly the same time as it is of strain rates 0.00167/s. Therefore in the dynamic region, the plateau stress of PVC foam with higher density increase faster than that with lower density. And as the two densities PVC foams themselves, the plateau stress increase faster than the density increasing, while it is indicated that when the PVC foams are applied as shield, heavier PVC foam may performed well within certain range even weight being considered.

Table 1. σ_n of the two density PVC of different strain rates.

Strain rates	σ_p (MPa)			
	P80	Difference	P160	Difference
0.00167	1.30	/	2.93	/
0.167	1.48	13.8%	3.32	13.3%
3025±2	1.65	26.9%	3.99	36.2%

The light PVC foams own the excellent energy absorption capability because of the ability of remaining nearly constant plateau stress in large plastic deformation. And the energy absorbed during compression, which is equals to the area under the strain-stress curve, is defined as:

$$W = \int_0^{\varepsilon} \sigma(e)\, de\,. \tag{1}$$

By doing the research on energy absorption characteristic of foam materials, an energy absorption efficiency parameter was presented Miltz and Ramon, (1990); Avalle et al. (2001). And the efficiency parameter was defined as a ratio between the absorbed energy up to a certain strain and the stress of the strain itself, as following:

$$E = \frac{1}{\sigma}\int_0^{\varepsilon} \sigma(e)\, de\,. \tag{2}$$

Energy absorption efficiency-stress curves under quasi-static loading of the two densities of PVC foams are shown in Fig. 4(a), and the peak efficiency of P80 foam is 48.1%, while the efficiency stress is 1.72 MPa, and the efficiency strain is 0.63; however the peak efficiency of P160 is 47.7%, while the efficiency stress is 3.25 MPa and the efficiency strain is 0.55. And it indicated that the efficiency stress of P160 is higher than that of P80. And the efficiency of lighter PVC foam is larger than that of heavier PVC foam, however the difference is very small. While the lighter PVC foams compressed more than that of heavier PVC foam when they reach their peak efficiency.

Energy absorption efficiency-stress curves under different strain rates of P160 foams are shown in Fig. 4(b). The curve of P160 foam in dynamic compression condition is not complete, because of the lack of loading intensity, but it is already indicated that as the loading rates increasing, the energy absorption efficiency, the efficiency stress and efficiency strain are all increasing. It means that when the strain rates increase, the PVC foam will absorb more energy in more efficient way.

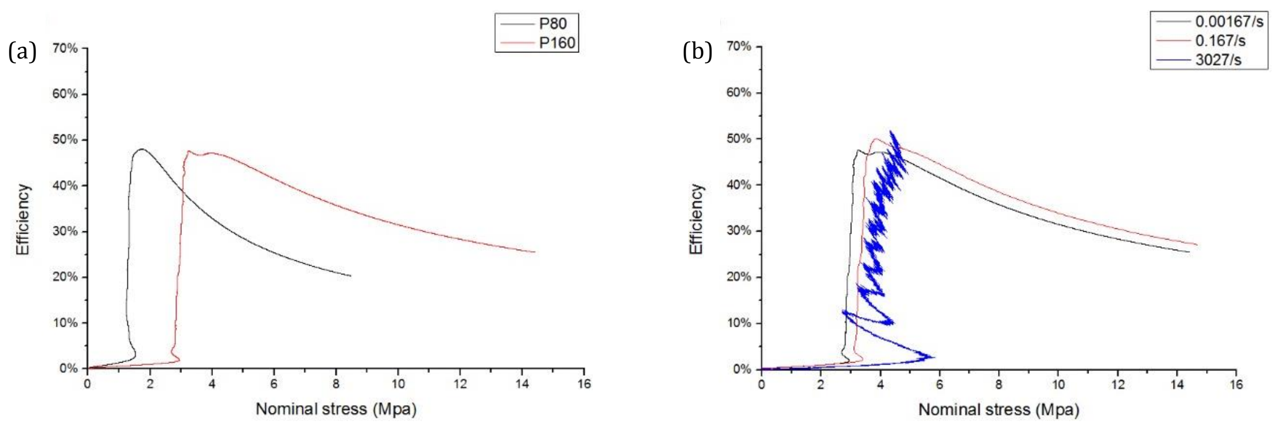

Fig. 4. Energy absorption efficiency-stress curves:
(a) two different densities of PVC foams; (b) three different strain rates of P160.

4. Conclusions

In this study, the high strain rates and quasi–static compression behaviors of two low densities of PVC foams, 80 kg/m^3 and 160 kg/m^3, are obtained by using split Hopkinson pressure bar and micro-controlled electronic universal testing machine. The results show that the strain-stress curves of PVC foams conclude three apparently stages, which are elastic stage, plateau stage and densification stage respectively. In certain density range, the PVC foams are strain rate sensitive materials. While in quasi-static loading conditions, the plateau stress of the two PVC foams increase in nearly same speed. Therefore in dynamic loading conditions, the plateau stress of PVC foam with higher density increase faster than that with lower density.

Energy absorption efficiency is also investigated in this study. And it shows that for different densities of PVC foams, the energy absorption efficiency of lighter PVC foam is larger but in small difference than that of heavier PVC foam, and the lighter PVC foams compressed more than that of heavier PVC foam when they reach their peak efficiency. While the efficiency stress of P160 is higher than that of P80. Therefore by comparing the energy absorption efficiency of different strain rates, it shows that the energy absorption efficiency, the efficiency stress and efficiency strain all increase as the strain rates increasing.

Acknowledgements

The authors would like to thank the National Natural Science Foundation of China (No. 11372088) for supporting the present work.

References

Avachat S, Zhou M (2015). High-speed digital imaging and computational modeling of dynamic failure in compo site structures subjected to underwater impulsive loads. *International Journal of Impact Engineering*, 77, 147-165.

Avalle M, Belingardi G, Montanini R (2001). Characterization of polymeric structural foams under compressive impact loading by means of energy-absorption diagram. *International Journal of Impact Engineering*, 25, 455-472.

Deshpande VS, Fleck NA (2005). One-dimensional response of sandwich plates to underwater shock loading. *Journal of the Mechanics and Physics of Solids*, 53, 2347–2383.

Fleck NA, Deshpande VS (2004). The resistance of clamped sandwich beams to shock loading. *Journal of Applied Mechanics*, 71(3), 386-401.

Miltz J, Ramon O (1990). Energy absorption characteristics of polymeric foams used as cushioning materials. *Polymer Engineering and Science*, 30(2), 129–133.

Qiu X, Deshpande VS, Fleck NA (2004). Dynamic response of a clamped circular sandwich plate subject to shock loading. *Journal of Applied Mechanics*, 71(5), 637-645.

Radford DD, McShane GJ, Deshpande VS et al. (2006). The response of clamped sandwich plates with metallic foam cores to simulated blast loading. *International Journal of Solids and Structures*, 43, 2243–2259.

Xu A, Vodenitcharova T, Kabir K (2014). Finite element analysis of indentation of aluminum foam and sandwich panels with aluminum foam core. *Materials Science and Engineering: A*, 599, 125-133.

Yuan JY, Chen X, Zhou WW (2015). Study on quasi-static compressive properties of aluminum foam-epoxy resin compo site structures. *Composites Part B: Engineering*, 79, 301-310.

Zhu F, Wang Z, Lu G (2009). Analytical investigation and optimal design of sandwich panels subjected to shock loading. *Materials and Design*, 30, 91-100.

Zhu F, Wang ZHH, Lu GX (2010). Some theoretical considerations on the dynamic response of sandwich structures under impulsive loading. *International Journal of Impact Engineering*, 37, 625–637.