A new method for dynamic shear-compression loading on cellular materials

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Abstract. This paper presents a new method based on the split Hopkinson pressure bar(SHPB) to perform impact combined shear-compression test for cellular materials. Such a testing method is validated by simulating the whole loading process with ABAQUS code. At last, this loading system is applied to test the shear and normal behaviors of 3003 aluminum honeycomb at different loading states.

Introduction

Cellular materials are widely used as energy absorbers in accidental or designed impacts. As the impact directions are usually unanticipated, the energy absorbing components are always found under complex loading condition, and one should actually consider the dynamic behavior of cellular materials under multiaxial loading such as combined shear-compression loadings.

In the past decades, researchers developed various quasi-static multiaxial loading apparatus based on MTS or custom-built machines [1] to study the crushing behaviors of cellular materials. However, as to the dynamic multiaxial loading which is closer to the realistic working condition of cellular materials in energy absorption applications, very limited works can be found in the open literatures [2, 3].

In this study, a Rotatable Hopkinson Bar (RHB) system is proposed to realize dynamic combined shear-compression loading on cellular materials. Validating works are performed by numerically simulating the whole loading process by using FEM. Finally, the dynamic combined shear-compressive behaviors of honeycomb are obtained by using this system.

RHB system Set-up

The RHB system proposed in this study is schematically shown in Fig. 1. The input and output bars are made of Nylon (PA66) with a diameter of 97mm and a length of 4m. The input bar has a beveled end at its specimen side. The incline angle of the bevel should be changed according to the combined shear-compressive loading states. The output bar is rotated by a turntable from loading angle $\theta=0^o$ (corresponding to uniaxial compression) to $\theta=60^o$ and aligns with the normal direction of the beveled end of input bar. The specimen is placed between the angled input and output bars.

It is assumed that equilibrium in the specimen and its neighboring contact parts with input and output bars is reached during the loading process, the forces acting on the specimen and its neighboring parts are shown schematically in Fig. 2. The equilibrium conditions along the bar axial directions (x_1 and x_1') are as follows:

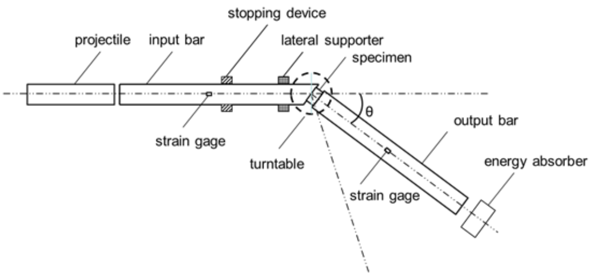


Fig. 1 Experimental set-up of RHB system

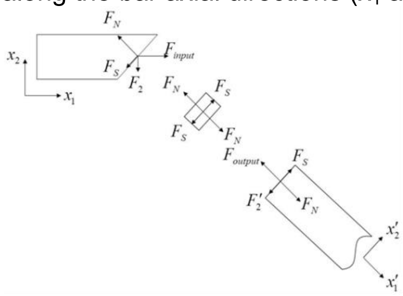


Fig. 2 Force equilibrium

$$F_{input} = F_N \cos\theta + F_S \sin\theta \quad (1)$$

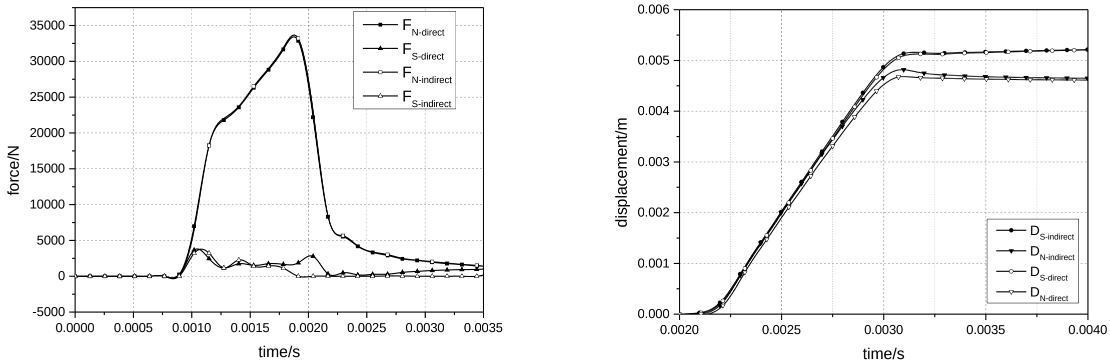
$$F_{output} = F_N \quad (2)$$

Where F_{input} and F_{output} are the forces acting respectively on the input and output bar which can be obtained from the three basic waves as done in traditional SHPB. θ is the shear-compressive loading angle. Thus, the normal and shear forces F_N and F_S can be calculated from equ. (1) and (2) without to know those lateral forces (F_2 and F_2' as shown in Fig. 2).

Numerical validations of RHB system

A numerical testing set-up is modeled by ABAQUS Explicit. The entire model on real size experimental apparatus is composed of the projectile, the input and output bars with an angle of 40^o, and a cylindrical specimen with dimensions of Φ60mm*15mm. The geometrical model is discretized by 8-node linear brick element with reduced integration and hourglass control (C3D8R). A bilinear elasto-plastic material model with man-made parameters is chosen for the sake of simplicity. Linear elastic material with viscoelastic constants is employed for the Nylon bars in order to include the wave dispersion effect. Surface-to-surface contact with rough shear property is employed for the interaction between specimen and two bars to avoid relative slip at bar-specimen faces. The impact velocity of projectile is taken the same value of 8m/s as used in experiments.

The feasibility of this RHB system is validated by comparing the shear-compressive behaviors of honeycomb from direct and indirect results (as shown in Fig. 3). The indirect results are the normal and shear behaviors calculated from the measurements (LE33) of the midpoint nodes according to equation (1) and (2) as done in experiments, and the direct results are the ones acting on specimen faces which can be extracted directly from the simulating results. It is found in Fig. 3 that the normal force obtained from the indirect result is corresponding well to the real normal force (direct) acting on the specimen faces. While, for the shear force, the indirect result contains much fluctuations comparing to the smooth direct result, but they are in coincident in average value. As to the deformations, the indirect results can also represent well the direct results.



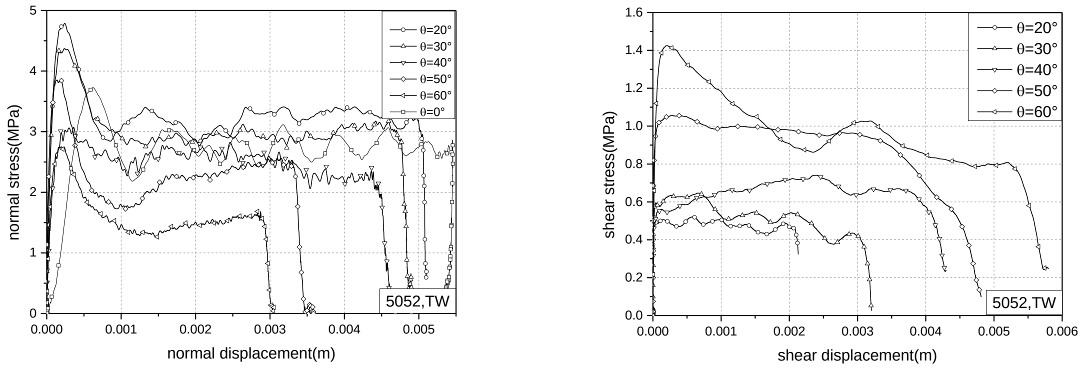
(a) (b)

Fig. 3 Comparison of forces(a) and displacements(b) between the calculating results from midpoint strain and the direct results acting on specimen faces

Applications

The hexagonal honeycomb used in the verifying test is made of 3003H18 aluminum alloy and possesses a relative density of about 4.1%. The specimen is in cylindrical geometry with a diameter of 60mm and a height of 15mm. The combined shear-compression loading is applied on the TW direction with different loading angles ranging from 0o(corresponding to uniaxial compression), 20o, 30o, 40o, 50o and 60o,The impacting velocity of the projectile is about 8m/s.

The separated stress/displacement curves of honeycombs under combined shear-compression are shown in Fig. 4. It is found that the normal strength of the honeycombs decreases with the increasing loading angle, while the shear strength increases. This results confirm our previous testing results and reveals that the shear component will weaken the compressive strength of the honeycomb at high strain rate.



(a) (b)

Fig. 4 Normal stress/normal displacement curves(a) and shear stress/shear displacement curves(b) for AL- honeycomb under various combined Shear- compression loading states

Conclusion

A new method based on SHPB is developed to perform impact combined shear-compression test for cellular materials. The validating work shows that this combined shear-compression method provides a quite accurate measurement on the specimen forces in both shear and normal directions. The experiment results show that the normal strength of the honeycombs decreases, while the shear strength increases with the loading angle.

References

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