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Dynamic energy absorption behavior of lattice material filled with shear thickening fluid

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Abstract

In the present research the dynamic energy absorption behavior of lattice material filled with shear thickening fluid (STF) is studied by the modified split Hopkinson pressure bar (SHPB) apparatus. The nominal engineering stresses versus strain curves are measured to analyze the dynamic energy absorption behavior of the combined material. The dynamic behavior of lattice material is also measured as a comparison. The results show the dynamic strength of the lattice material is about 3 MPa, which is a little higher than the static strength of about 2.3 MPa because of the inertial effect during impact. However, when filled with STF, the combined material shows extraordinary energy absorption behavior when compared to the empty lattice material. The stress of the lattice material filled with STF increase almost linearly to about 9 MPa and then increases slowly with the increase of strain. The excellent energy absorption behavior of the lattice material filled with STF could be explained by the interaction between the lattice cores and the STF during compression. For the lattice material, while some of cores buckling, it will lose the load capacity. While filled with STF, if the initial buckling of some of the lattice cores happens during impact, the strong lateral drag force is generated by the ambient STF due to the fast lateral velocities of the cores, leading to the great increase of its dynamic energy absorption behavior.

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Keywords: Dynamic energy absorption behavior; Lattice material; Shear thickening fluid; Split Hopkinson pressure bar.

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1. Introduction

Dynamic energy absorption behavior of materials has attracted great attentions for many years. Many kinds of materials such as metal foams [1, 2] are found to show excellent high energy absorption capacity under dynamic compression. However, these materials such as metal foams generally experience large plastic deformation after a single impact with high impulse energy. As a result, the energy absorption capacities of these materials are irreversible, which restricts applications of these materials. Therefore, some smart materials with reversible energy absorption capacity are required in this situation.

Shear thickening fluid (STF) is one kind of smart materials that show reversible energy absorption behavior [3-5]. Also, STF shows excellent energy absorption capacity through viscos dissipation due to shear thickening behavior [4, 6-10]. It has been regarded as a kind of advanced materials for dynamic energy absorption. Some of researches have been performed to address the dynamic behavior of STF at various pressures and strain rates, showing high energy absorption behavior of STF [3, 4, 9-11].

As STFs are generally fluid-like state, it needs to be used with some porous materials and structures in practical applications [12-16]. Sandwich panels with lattice truss cores have attracted a lot of attentions of researchers for the past few years due to its lightweight, high strength/density ratio, as well as convenient fabrication [17]. Combining STF and sandwich panel with lattice truss core can bring a promising structural material with excellent multifunction, such as lightweight, high strength/density ratio, as well as reverse energy absorption behavior [3, 9, 10, 18, 19].

With this as a motivation, the dynamic behavior of sandwich panels with empty and STF filled pyramidal lattice truss cores at various impact velocities is investigated experimentally. In this study, the modified split Hopkinson bar is taken. The nominal stress versus strain relationships of the sandwich panels with empty and STF filled pyramidal lattice truss cores are analyzed.

2. Experiments

In the present study, SHPB apparatus is modified as Fig. 1 to investigate dynamic behavior of sandwich panels with empty and STF filled pyramidal lattice truss cores. The facility comprises a striker bar and an incident bar, all made from 19.05 mm diameter high-strength 7075-T6 aluminum alloy. A trumpet-shaped loading end with a thickness of 15 mm and a maximum diameter of 80 mm is employed. The trumpet-shaped end is also made from 7075-T6 aluminum alloy to minimize the impedance mismatch effect. The sandwich panel specimens are sandwiched between the loading end and a large hard steel disk that acts as a rigid support. The striker bar is accelerated using a compressed air gas-gun. A pair of semiconductor strain gages (SB5-120-P-2Y15) strategically attached on to the middle of the incident bar to record the strain pulses in the incident bar.

In a SHPB test with the aforementioned configuration, a compressed air gas-gun is used to accelerate the striker bar to impact the incident bar. The impact results in an elastic compression wave with a strain profile, denoted by $\varepsilon_I(t)$, which travels in the incident bar towards the sandwich panel specimen. Part of the incident compressive wave is reflected back into the incident bar, denoted by $\varepsilon_R(t)$, while the rest is transmitted into the large hard tool-steel disk. Elementary 1D elastic wave-propagation equations are used to calculate the engineering stress $\sigma_S(t)$, the strain rate $\dot{\varepsilon}_S(t)$, and strain $\varepsilon_S(t)$ as

$$\sigma_S(t) = E\frac{A_0}{A_S}\left[\varepsilon_I(t) + \varepsilon_R(t)\right], \tag{1}$$

$$\dot{\varepsilon}_S(t) = -2\frac{c_0}{h_S}\varepsilon_R(t), \tag{2}$$

$$\varepsilon_S(t) = \int_0^t \dot{\varepsilon}_S(t)dt, \tag{3}$$

where E, A_0 and c_0 are Young's modulus, cross-sectional area, and longitudinal wave speed in the incident bar; A_S and h_S are the initial cross-sectional area and thickness of the specimen, respectively.

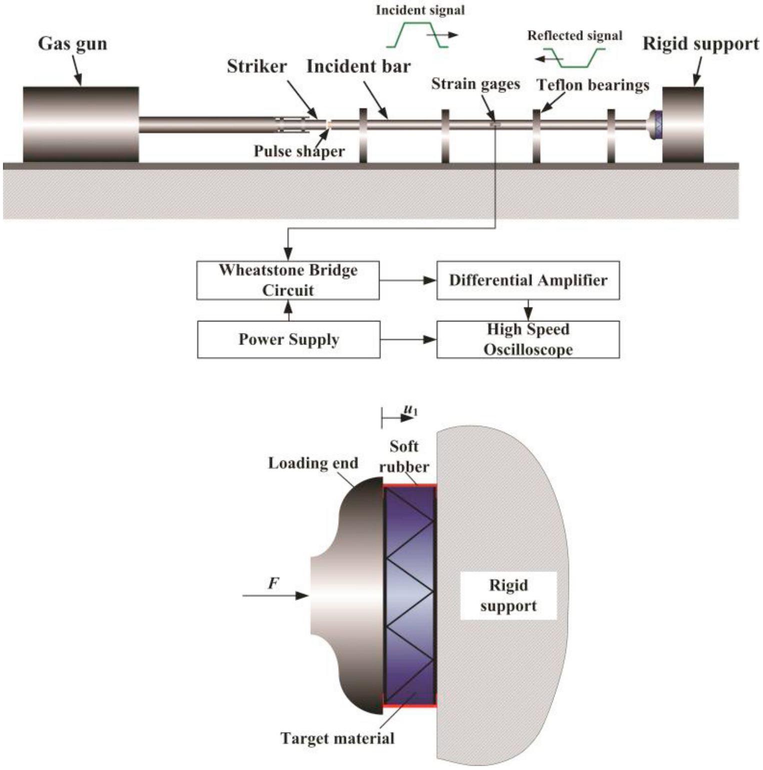

Fig. 1. Modified SHPB apparatus.

3. Results

The nominal stress versus strain relationship of the sandwich panel with empty pyramidal lattice truss cores at a strain rate of 900 s^{-1} is shown in Fig. 2. At the beginning, the stresses increase almost linearly with the increase of strain. Then the buckling of core beams happen, leading to the decreases of stresses. While the core beams contact with each other or with the panels, the stresses increase quickly once again. Strength is approximately 3.0 MPa at a strain rate of about 900 s^{-1}, which is about 50% higher than that obtained at quasi-static compression due to the lateral effects [20-22].

The measured result of the sandwich panels with STF filled pyramidal lattice truss cores at a strain rate of 840 s^{-1} is shown in Fig. 3. It can be seen that the stresses increase almost linearly to about 9.0 MPa, which increases by about 3 times when compared to the that with empty cores, showing significantly improved dynamic energy absorption capacity of the sandwich panels after filled with the STF.

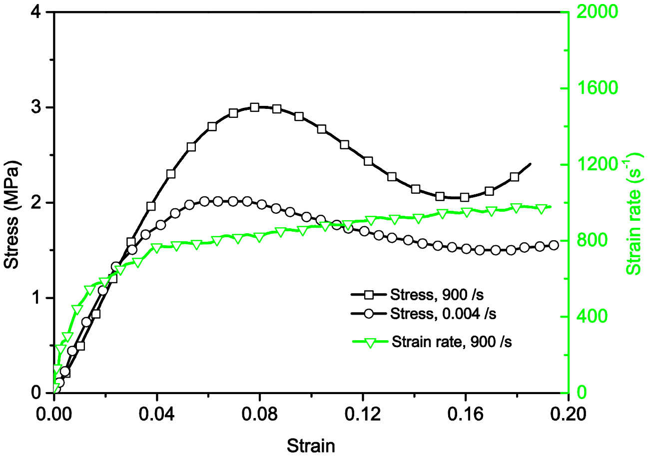

Fig. 2. Nominal stress versus strain relationships of the sandwich panels with empty pyramidal lattice truss cores.

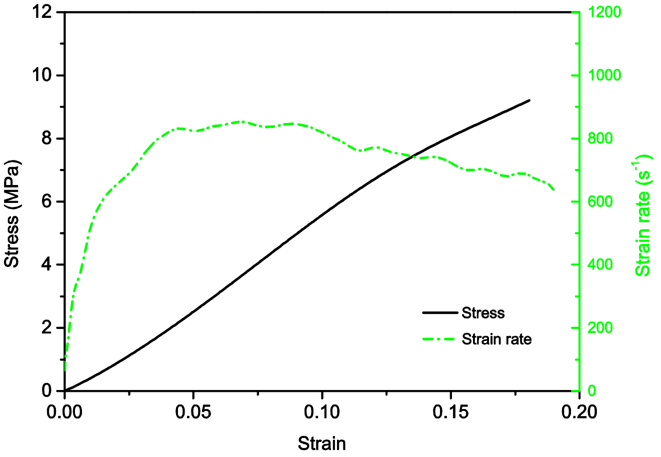

Fig. 3. Nominal stress versus strain relationships of the sandwich panels with STF filled pyramidal lattice truss cores at various strain rates.

4. Summary and Discussion

While filled with STF, the strength of the sandwich panel increases almost linearly to about 9.0 MPa, which is three times higher than that of the sandwich panel with empty pyramidal lattice truss core. The high dynamic energy absorption behavior of the sandwich panel with the STF filled pyramidal lattice truss core could be understood by the interaction between the filled STF and the pyramidal lattice core. After filled with the STF, the deformation modes of the unit cells are changed through strong interaction between the pyramidal lattice truss core and the filled STF material. Once the buckling behavior of the unit cells happen, the lateral velocities of the buckled beams are fast, leading to the fluid-solid state transition. Therefore, large drag forces are applied on the lateral surface of core beams and consequently increase the strength of the sandwich. The filled STF may also transform the deformation modes of core beams from symmetry to nonsymmetry, which will also significantly increase the energy absorption capacity of the sandwich panels. Further study will be conducted in future to better understand the interaction mechanism between the STF and the sandwich panel with pyramidal lattice truss core.

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