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Study on the effect of basalt fiber on the energy absorption characteristics of porous material ☆

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HIGHLIGHTS

- The energy-absorption indicators under different strain rate have been obtained.
- The energy-absorbing features and effect of basalt fiber have been analyzed.
- Basalt fiber has obvious improving effect on the toughness of porous material.
- Basalt fiber can improve the energy-absorbing ability of porous material.
- Basalt fiber has a promising future in the feature improving field.

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ABSTRACT

Ceramics–cement based porous material (CCPM) and basalt fiber reinforced ceramics–cement based porous material (BFRCCPM) have been prepared. The quasi-static compression test and impact compression test of both CCPM and BFRCCPM have been made and the energy-absorption indicators under different strain rate have been obtained. The energy-absorbing features of them have been comparatively analyzed and the effect of basalt fiber has been comparatively studied. The results show: under quasi-static compression state, the peak toughness and full toughness increase continuously with strain rate. Under the same strain rate, the peak toughness of BFRCCPM are obviously higher than that of CCPM. It is because basalt fiber can increase the peak toughness and full toughness. During impact compression stage, the peak toughness and specific energy absorption are highly strain rate sensitive and increase continuously with it. Basalt fiber has obvious improving effect on both peak toughness and full toughness. During impact compression state, the more energy the specimen absorbs, the more seriously it is damaged. BFRCCPM is comparatively slightly damaged given the same amount of absorbed energy. It is because the important effect of the basalt fiber. So, it can be concluded that basalt fiber can improve the energy-absorbing ability of porous material and has a promising future in the feature improving field.

1. Introduction

Porous material [1–3] is the composite of solid phase and its porous structure can change from perfectly structured beehive to disordered three-dimensional network like sponge or foam group. The most notable difference between porous material and entity-structured material is that porous material has its unique and delicate hole structures which gives it unique and comprehensive properties like low thermal conductivity, low permeability, good damping capacity, low density, excellent mechanical properties, and the greatest of these is outstanding energy absorption characteristic. At present, the worldwide researches on energy-absorbing materials mainly focus on porous materials, including high polymer and foamed metal materials, such as polyurethane foam [4,5] and foamed aluminum [6,7]. However, these materials are complicated to prepare, too expensive or unsatisfying in strength or plasticity, so new porous materials need to be developed urgently to overcome those disadvantages. Ceramics–cement based porous material (CCPM) is newly developed energy-absorbing material that belongs to the category of both cement-based

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composite material and inorganic porous material. Combining the advantages of cement-based composite material and porous material, it can show the superimposed effect, and overcome the disadvantages of traditional energy-absorbing materials. The improvement of material is endless, so how to increase the energy-absorbing ability of CCPM is a topic worthy of in-depth study.

Basalt fiber [8] is a new type of environmentally friendly material with many exceeding properties for it is high temperature resistant, acid and alkali resistant and has exceeding mechanical properties and high insurability. Numerous researches [9,10] indicate that basalt fiber is excellent in improving the properties of other materials and has a great developing prospect.

In this paper, cementitious materials, ceramic aggregates and fiber are used as basic materials. And based on Dense Packing Theory, basalt fiber reinforced ceramics–cement based porous material (BFRCCPM) is prepared with basalt fiber content of 0, 0.2% (in volume). The quasi-static compression test and impact compression test of both CCPM and BFRCCPM have been made and the energy-absorption indicators under different strain rate have been obtained. The energy-absorbing features of BFRCCPM have been comparatively analyzed and the effect of basalt fiber has been comparatively studied.

2. Experimental details

2.1. Raw materials

The ingredients to prepare BFRCCPM are mainly cementitious materials, ceramic aggregates and fiber.

Cementitious materials: ① cement: 42.5R ordinary Portland cement; ② fly ash: parameters reach level of class I; ③ silica fume: average particle size is between 0.1 and 0.15 μm, 15 and 27 m^2/g specific surface area, 92% SiO_2 content; ④ superplasticizer: 20% water-reducing rate; ⑤ water: drinking water.

Ceramic aggregates: ① alumina hollow balls: four parts of particle size level (0.2–1.0 mm, 1.0–2.0 mm, 2.0–3.0 mm, 3.0 mm–5.0 mm), Al_2O_3 >99%, compressive strength at normal temperature >8Mpa; ② ceramsite: packing density is 510 kg/m^3, cylinder pressure strength ⩾1.5 Mpa, water absorption ⩽15%, shape coefficient is “globular shape ⩽1.6”.

Fiber: basalt fiber, 15 μm in filament diameter, chopped length 18 mm, density 2650 kg/m^3, young’s modulus 93–110GPa, tensile strength 4150–4800 MPa, ultimate elongation in percent 3.1%.

2.2. Mixture ratio design

The dense accumulation of particle system has great influence on many industrial fields and the core technique of it is how to apply Dense Accumulation Theory [11,12]. The fact that composite materials can be made from various raw materials makes it possible to apply the theory.

According to Dense Packing Theory, the mixture ratio of CCPM is presented every 1 m^3: 386 kg cement, 213.5 kg fly ash, 29.68 kg micro-silica, 5.93 kg superplasticizer, 184 kg water, 352 kg ceramsite and 226 kg alumina hollow balls. When BFRCCPM is prepared with fiber content of 0.2% (in volume), the weight of basalt fiber is 5.3 kg every 1m^3. The approach to form the hole structures is important for porous material, for CCPM, alumina hollow balls with four parts of particle size level, the volume ratio of which is 73:9:10:8, are used, and ceramsite is filled with small pores, which can guarantee the combination holes in different sizes.

2.3. Preparation method

A 60 L forced mixer is used. Considering the characteristics of the materials, the alumina hollow balls and ceramsites should be mixed as follows: 1. Mix superplasticizer and water up in advance, and keep the superplasticizer solution for the following steps; 2. Stir the micro-silica and half amount of the cement for 30 s. 2. Add half amount of superplasticizer solution and continue to stir for 30 s. 3. Add the ceramsites and stir for another 30 s; 4. Add the rest of superplasticizer solution and cement, stir the mixture for another 120 s, and the uniform mixture is made. Put the mixture out of the mixer, and manually blend it while sprinkling the alumina hollow balls and basalt fiber.

The preparation of the specimen: Put the specimen in natural condition and remove it from the mould after 24 h. Right after the removal, maintain the specimen in standardized condition ($T = 20 \pm 2$ °C, relative humanity >95%); 28 days later, polish the specimen with a waterstone (Regulate the parallelity of the end faces and the surface flatness), and the geometric dimension of the specimen is about $\Phi 95 \times 50$ mm.

3. Testing method

3.1. Quasi static mechanics testing

A quasi-static compression test of BFRCCPM is made with improved HHY series electro-hydraulic servo system. Under different strain rates, to test the quasi static compression properties of CCPM, the loaded strain speeds should be constant. They are 600 $\mu\varepsilon/$min, 6000 $\mu\varepsilon/$min, 12,000 $\mu\varepsilon/$min, which can be converted into strain rates $\dot{\varepsilon}$, $1 \times 10^{-5}s^{-1}$, $1 \times 10^{-4}\,s^{-1}$, $2 \times 10^{-4}\,s^{-1}$ respectively.

After data processing, the stress-strain curves of CCPM and BFRCCPM under quasi static state and three different strain rates are obtained, as is shown in Fig. 1.

According to Fig. 1, the stress-strain curves of CCPM and BFRCCPM share some features in common. At the initial loading stage, stress goes up sharply with strain, which shows obvious elasticity. While when it comes to the peak value, there appears stress plateau. That is to say, with the increase of strain, stress is unstable above some level until final brittle failure. So, the stress-strain curves obviously have three clear stages: elasticity stage, stress plateau stage and softening and damaging stage.

3.2. Impact compression test

A 100-mm-diameter split Hopkinson pressure bar (SHPB) is used for testing, and this apparatus consists of main body, energy source and measurement systems. Main body mainly includes launch tube, projectile, incident bar, transmission bar and energy absorbing setup; energy source system mainly includes air compressor, pressure vessel; measurement system includes velocity and dynamic strain measurement setup.

The propagation process of stress pulse in the SHPB apparatus can be described as follows: the impact of the striker bar at the incident bar generates an elastic strain wave, which is called incident pulse that propagates through the incident bar and reaches the incident bar-specimen interface. While a part of the incident pulse is reflected back into the incident bar, the rest of it propagates through the specimen and generates the transmitted pulse in the transmitted bar. The test validity mainly depends on the Stress equilibrium and constant strain rate loading.

In order to improve the accuracy of the test of dynamic mechanical properties, pulse shaping technique [13,14] is applied to the SHPB apparatus,

In this study, H62 brass pulse shapers of different geometries i.e. 1 mm thickness and 20, 22, 25, 27 and 30 mm diameter, are designed to improve incident waveforms. wave oscillation is eliminated by using pulse shaping technique, and then the half-sine-like stress pulse is obtained. From the perspective of

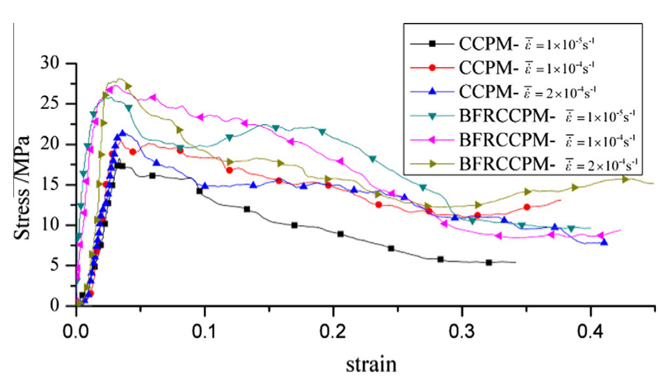

Fig. 1. Quasi static stress–strain curves.