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Technical note

The static constitutive model of fiber reinforced cellular materials

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ABSTRACT

Fiber reinforced cellular materials (BFRCMs) are prepared with fiber content of 0.2% (in volume). The quasi-static compression experiments have been carried out, the stress-strain curves have been worked out and a new math model has been created to establish the static constitutive model of BFRCMs. The results indicate that, BFRCMs have the successively sized cellular structures and a wide plateau stage in the static stress-strain curve, and BFRCMs are ideal energy absorbing material; the static constitutive relation has good coherence with stress-strain curves; the static constitutive model of BFRCMs can be applied in practical projects and numerical simulation. Thus it can be seen, the new math model has broad application prospects in the static constitutive model of cellular materials.

1. Introduction

Cellular material [1–3] is the composite of solid phase and the holes developed from it, whose structure can change from perfectly structured beehive to disordered three-dimensional network like sponge or foam group. The most notable difference between cellular material and entity structure material is that the former has unique mechanical properties, and finds increasing application in engineering, especially in the field of impact and blast protection. At present, the worldwide researches on cellular materials mainly focus on high polymer and foamed metal materials, such as polyurethane foam [4] and foamed aluminum [5,6]. However, these materials are complicated to prepare, expensive or unsatisfying in strength or plasticity, so new cellular materials need to be developed urgently to overcome those disadvantages.

In this paper, cementitious materials, porous aggregates (or lightweight aggregates) and fiber are used as basic materials; basalt fiber reinforced cellular materials (BFRCMs) are prepared with fiber content of 0.2% (in volume). The cellular materials refer to the composite material made by stirring, shaping, and maintaining properly proportioned jelling material, fine aggregate, thick aggregate and water. As a new cellular material, it would be meaningful to explore the relationship of stress and strain. Moreover, using a correct material constitutive equation is the foundation to set up a mechanics model. So, the constitutive models of new cellular materials need to be done urgently to accelerate the application and development of cellular material.

With the improved HYY electro-hydraulic servo system, the quasi-static compression experiment on BFRCMs has been carried out. The stress-strain curves have been worked out, and a new math model has been created to establish the static constitutive model of BFRCMs.

2. Materials and methods

2.1. Raw materials

The ingredients to prepare BFRCMs are mainly fiber, cementitious materials (cement based cementitious material or geopolymer [7–9] based cementitious material) and aggregates (porous aggregates or lightweight aggregates), and their basic features are as follows.

Fiber: Basalt fiber, 15 μm in filament diameter, chopped length 18 mm, young's modulus 93–110 GPa, tensile strength 4150–4800 MPa, ultimate elongation 3.1%.

Cement based cementitious material: Cement, 42.5R; Fly ash, class I; Silica fume, average particle size is between 0.1–0.15 μm, 15–27 m^2/g specific surface area; Superplasticizer, 20% water-reducing rate; Drinking water.

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Geopolymer based cementitious material: Fly ash, class I; Slag, the specific surface area is 491.6 m^2/kg, activity index ≥95%; NaOH, analytically pure, content ≥99.0%; Liquid sodium silicate (LSS), the modulus range is between 3.0 and 3.3.

Porous aggregates: alumina hollow ball (AHB), a kind of new material, is mainly featured by its nanometer measured shell and spacious inside; Ceramsite, packing density is 510 kg/m^3, cylinder pressure strength ≥1.5 MPa, water absorption ≤15%.

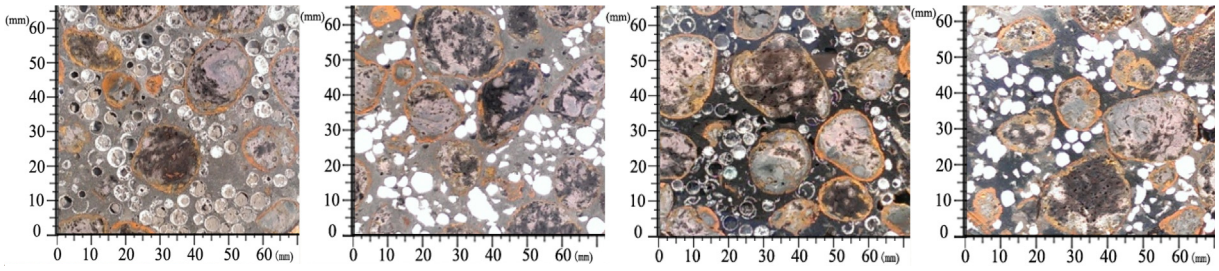
Lightweight aggregates: Recycled expanded polystyrene (EPS), 3–5 mm diameter; Ceramsite.

2.2. Mixture ratio design

Based on the dense packing theory, according to the target grading of "minimum void ratio, minimum specific surface area, maximum bulk density", four kinds of BFRCMs have been prepared with the above raw materials and these kinds of BFRCMs can be identified as BFRCMs(F1), BFRCMs(S2), BFRCMs(T3) and BFRCMs(FO4) respectively. The mixture ratio of BFRCMs presented every 1 m^3 is shown in Table 1, where W/P ratio refer to the mass ratio between water and powder material.

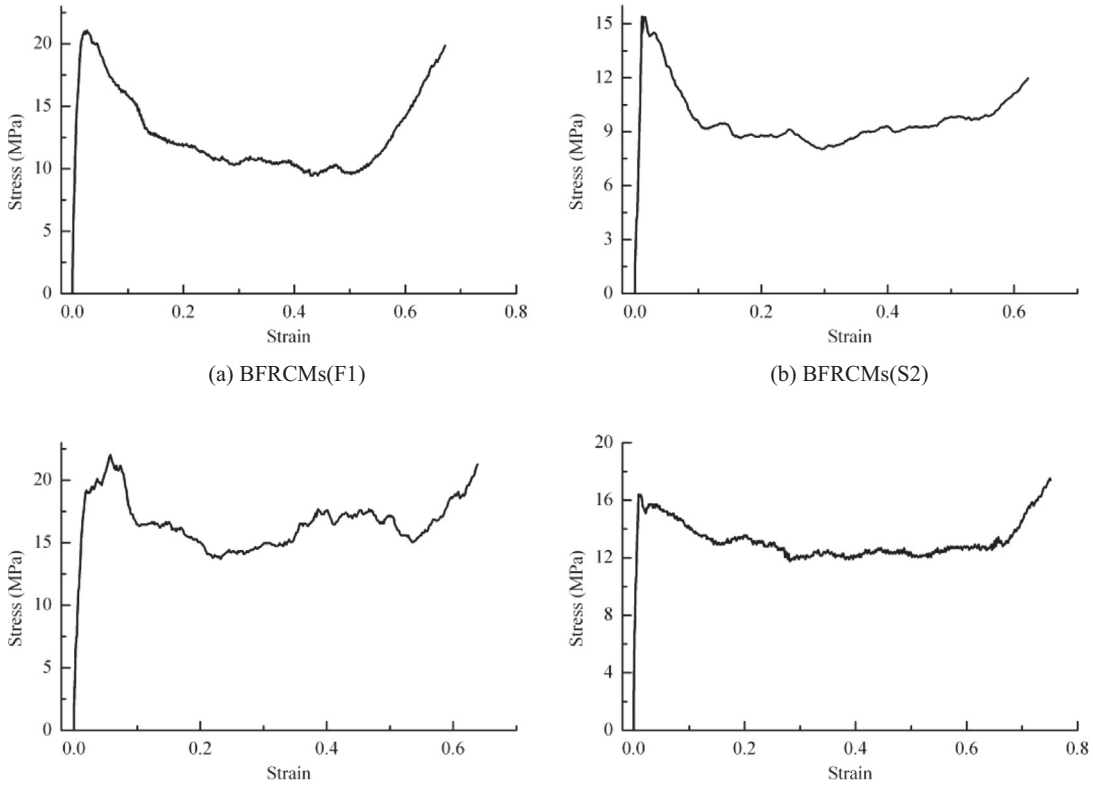
Table 1
The mixture ratio of BFRCMs.

Components BFRCMs	Cementitious materials						Aggregates		Basalt fiber
	Powder material (P)			Solution		W/P ratio			
F1	386 kg cement	213.5 kg fly ash	29.68 kg micro-silica	5.93 kg superplasticizer	184 kg water (W)	0.292	339.60 kg ceramsite	218.02 kg AHB	5.3 kg
S2							362.00 kg ceramsite	2.50 kg EPS	
T3	300 kg slag	100 kg fly ash	–	38.40 kg NaOH	134.4 kg water (W)	0.336	334.31 kg ceramsite	193.13 kg AHB	
FO4				134.40 kg LSS			334.31 kg ceramsite	2.32 kg EPS	



(a) BFRCMs(F1) (b) BFRCMs(S2) (c) BFRCMs(T3) (d) BFRCMs(FO4)

Fig. 1. Cellular structures.



(a) BFRCMs(F1) (b) BFRCMs(S2)

(c) BFRCMs(T3) (d) BFRCMs(FO4)

Fig. 2. The quasi-static stress-strain curves.