Supporting Information

Bio-Inspired Sinusoidal Metamaterials: Design, 4D Printing, Energy-Absorbing Properties

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S1. Evaluation index of energy-absorbing performance

Regarding structures that buffer energy absorption, some criteria for energy absorption performance have been proposed by relevant researchers. The carrying capacity and energy absorption capacity can be quantified using common metrics such as total energy absorption (EA) and specific energy absorption (SEA).

(1) Total Energy Absorption EA

The force-displacement curve of a structural specimen compressed to a dense state is integrated to characterize the ability of the structural specimen to absorb energy through deformation, i.e:

$$EA = \int_0^{\delta} F dx \tag{S1-1}$$

Where EA is the total absorbed energy; F is the load; and δ is the dense point.

(2) Specific energy absorption SEA

For the lightweight structure and the need of effective energy absorption evaluation, the specific energy absorption coefficient (SEA) is used as the key index to evaluate the energy absorption performance of porous materials, i.e:

$$SEA = \frac{EA}{M} \tag{S1-2}$$

Where SEA is the mass specific energy absorption; M is the mass of the specimen.

S2. Phase transition properties of PLA

To further understand the phase transition properties of PLA filaments, a differential scanning calorimeter (DSC25, TA Instruments, USA) was utilized to determine the phase transition of the material. The whole test was carried out under nitrogen protection for the whole process experiment of heating-up-cooling-down, heating-up-cooling-down, the first heating was done to eliminate the thermal history of the material, so the second scanning data was used as the test result. The temperature range was set from room temperature to 220°C, and the rate of heating and cooling was 10°C/min.

PLA is a typical shape memory polymer, so we utilized a differential calorimetric scanner (DSC) to determine the thermal transition process of the PLA material during the rise and fall of the temperature of the material, and the test results are displayed in Figure S1. The figure shows the secondary elevated temperature DSC curve of the PLA material. From the figure, it can be found that a downward heat absorption phase, an upward exothermic peak and a downward heat absorption peak appear in the secondary elevated temperature DSC curve from left to right, which represents that the composite material undergoes a glass transition, a post-crystallization transition, and a melting transition, respectively, in the process of elevated temperature. In this study, we need to focus on the Tg temperature of the material, according to the free volume theory, Tg is considered to be the free volume of the polymer that decreases when it cools down and reaches a certain critical temperature, due to the molecular chain segments movement is frozen, the free volume is also frozen and maintains a constant value, which is Tg. When the temperature is gradually increased to reach the glass transition point, the free volume begins to unfreeze, and the chain segments gain enough movement and free space to move from the frozen state to the melt transition, and the free space and energy are increased. According to the DSC test results, it can be found that the Tg temperature of PLA material is 58.63℃.

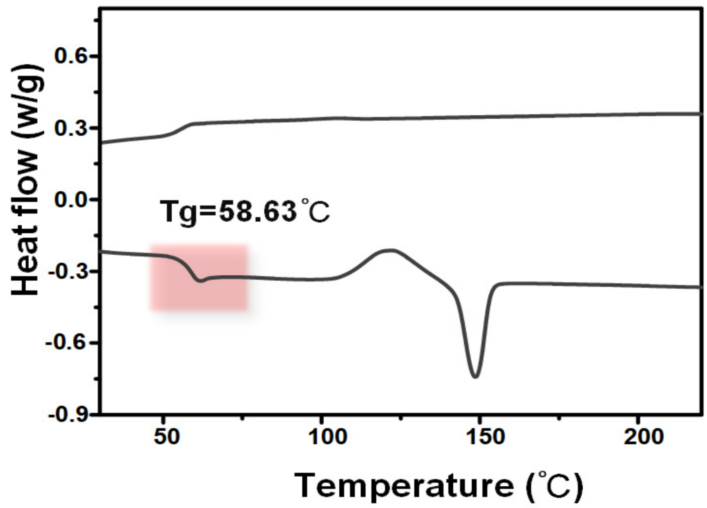

Figure S1. DSC curve of PLA.