COMPOSITES WITH ENHANCED CONDUCTIVITY AND YOUNG'S MODULUS AND DESIRED POISSON'S RATIO

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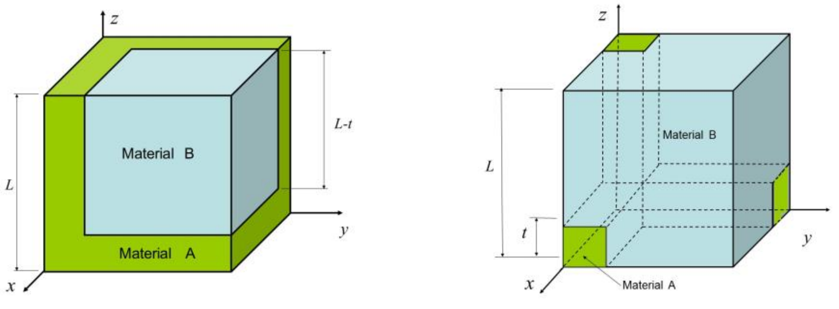
Summary We have designed two types of composites with size from macro- down to micro- and nano-scale. One type of the composites has an isotropic conductivity almost the same as the maximum possible upper limit, and the other type has an isotropic conductivity much greater than the conventional isotropic composites. The designed two types of composites can have an almost isotropic Young's modulus significantly greater than the Voigt limit and a Poisson's ratio at a desired value, e.g. positive, negative or 0. The designed composites have wide applications in many different structures from space aircrafts, land vehicles/buildings to underwater submarines.

GEOMETRICAL STRUCTURE OF THE COMPOSITES

We have designed two types of composites [1, 2], which are made of two different isotropic constituent materials, filler A and matrix B. The Young's moduli of the two constituent materials are assumed to be E_A and E_B, the Poisson ratios to be ν_A and ν_B, and the conductivities to be μ_A and μ_B, respectively. In the type-I composites, material A is assumed to have the geometrical structure of a perfect regular closed-cell foam with a large number of identical cubic cells of edge length L and square cell walls of uniform thickness t; material B is assumed to be identical cubes of edge length L-t, which are located at each of the cell centers of material A. Fig. 1(a) shows the representative volume element (RVE) of the type-I composites. In the type-II composites, material A is assumed to have the geometrical structure of a perfect regular open-cell foam with a large number of identical cubic cells which have uniform edges of length L and square cross-section of side t; material B is the matrix which fills the space of material A. The representative volume element (RVE) of the type-II composites is shown in Fig. 1(b).



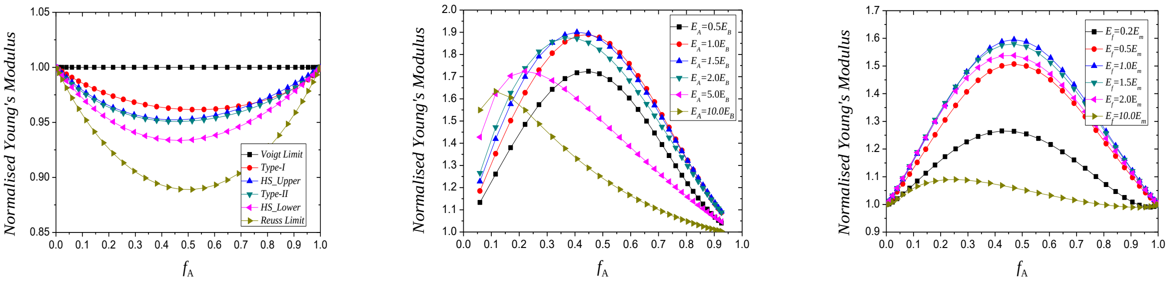
(a) Type-I (b) Type-II

Fig. 1. Cubic periodic representative volume elements (RVEs) of the two types of composite materials.

ELASTIC PROPERTIES OF THE COMPOSITES

1. Enhanced Young's modulus

As the two types of composites have cubic symmetry, they have only three independent elastic constants [3] and are almost isotropic. When $E_A = 2E_B$ and $\nu_A = \nu_B$, the relationship between the Young's modulus of the composites and the volume fraction of material A is shown in Fig. 2(a), where Young's modulus is normalized by the Voigt limit. The Hashin—Shtrikman's upper and lower bounds, and the Reuss limit are also included for comparison. As can be seen in Fig. 2(a), when the effects of the Poisson ratios are absent (i.e. $\nu_A = \nu_B$), the type-I composites are in general stiffer than



(a) (b) (c)

Fig. 2. Relationship between the Young's modulus of the composites and the volume fraction of material A.

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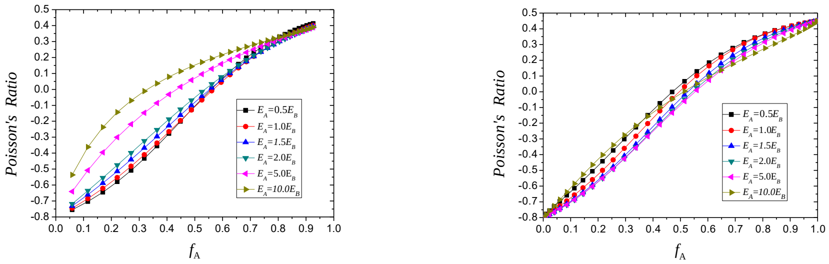
the Hashin-Shtrikman's upper limit, and the stiffness of the type-II composites is very close to the Hashin-Shtrikman's upper limit and much greater than their lower limit. As the Hashin-Shtrikman's upper limit is generally recognized as an unexceedable upper limit for isotropic composites when the effects of the Poisson's ratios are absent, the results in Fig. 2(a) clearly demonstrate that the designed structures of the two types of composites can significantly enhance the stiffness of composites [1, 2]. For isotropic solid materials, the value of the Poisson's ratio is in the range between 0.5 and -1.0. When $\nu_A = 0.45$ and $\nu_B = -0.8$, the relationships between the effective Young's modulus of the two types of the designed composites and the volume fraction of materials A are shown in Figures 2(b) and 2(c), where the Young's modulus is normalized by the Voigt limit. As can be seen, for different combinations between the Young's moduli of materials A and B, the normalized Young's moduli of the composites are much larger than 1.0, and hence much larger than the Voigt limit [1, 2].

2. Desired Poisson's ratio

When $\nu_A = 0.45$ and $\nu_B = -0.8$, the relationships between the effective Poisson's ratio of the two types of the designed composites and the volume fraction of materials A are shown in Figures 2(b) and 2(c). As can be clearly seen, the Poisson's ratio of the composites could be designed to have a desired value, e.g. positive, negative or 0 [1, 2].



(a) Type-I (b) Type-II

Fig. 3. Relationship between the Poisson's ratio of the composites and the volume fraction of material A.

CONDUCTIVITIES OF THE COMPOSITES

When $\mu_A = 10\mu_B$, the relationship between the normalised effective conductivity of the two types of composites and the volume fraction of material A is presented in Fig. 4, where the Voigt limit, the Hashin-Shtrikman's upper and lower limits and the Reuss limit are included for comparison. The Hashin-Shtrikman's upper limit is generally recognized as an unexceedable upper limit for the conductivity of isotropic composites. As can be seen, the structure of the type-I composites can maximize the isotropic conductivity and the type-II composites have an isotropic conductivity very close to the Hashin-Shtrikman's upper limit and much greater than their lower limit [4].

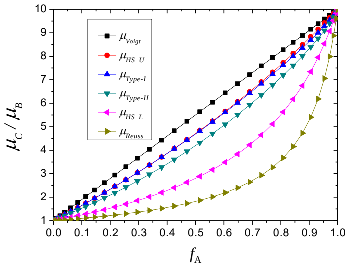


Fig. 4. Comparison between the conductivities of the two types of composites and the well known limits.

CONCLUSIONS

The designed two types of composites have not only enhanced stiffness and conductivity, but also a desired value of Poisson's ratio. The size of the designed composites can be at macro- down to micro- and nano-scale. They have very important applications in many different structures from space aircrafts, land vehicles/buildings to underwater submarines.

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