Solid materials with anisotropic stiffness and inertial mass simultaneously, which we denote as 'dual anisotropy', are critical for manipulating acoustic and elastic wave propagation. Usually, anisotropic mass is designed through the concept of resonance, thereby is available only in the narrow frequency band. In this work, we have designed all-solid metamaterials with nearly dispersionless dual-anisotropic properties in a broad frequency range. Results have been validated through the band-structure and effective-medium analyses. These studies pave the way to the technological realization of broadband solid metamaterials with potential applications to acoustic and elastic wave controlling.

Keywords: metamaterials, dual-anisotropic, non-dispersive, wave controlling, transformation

1. Introduction

Anisotropic properties expected from metamaterials are thought to be pivotal factors for bending a wave trajectory in the reflectionless manner. Simultaneous anisotropic stiffness and mass density are demanded in a general sense, which we denote as 'dual anisotropy'. There has been a long history of studies exploiting solid structures with anisotropic elasticity[1]. Anisotropic inertial mass is usually acquired by introducing different frequencies at various directions and is inevitably accompanied with the strong dispersion, resulting in a narrow band of operating frequency[2-3]. The challenge for designing the dual-anisotropic solid metamaterials is to broaden the anisotropic-mass bandwidth, as is currently unavailable through the concept of resonance.

2. Models and results

The proposed 2D dual-anisotropic metasolid is shown in Fig. 1. Broadband anisotropic density is to be realized due to the sharpened bar inclusions, wherein the slender cross-sections are made for pursuing a very small connecting stiffness in order to broaden the anisotropic-mass bandwidth. The constitutive equation governing the orthotropic elasticity is given by

\[
\begin{bmatrix}
\sigma_{xx} \\
\sigma_{yy} \\
\sigma_{xy}
\end{bmatrix} =
\begin{bmatrix}
\epsilon_{11} & \epsilon_{12} & 0 \\
\epsilon_{21} & \epsilon_{22} & 0 \\
0 & 0 & \epsilon_{44}
\end{bmatrix}
\begin{bmatrix}
\sigma_{xx} \\
\sigma_{yy} \\
\sigma_{xy}
\end{bmatrix}
\]

(1)

The equation of inertial motion that defines the anisotropic density reads

\[
\begin{bmatrix}
F_x \\
F_y
\end{bmatrix} = -\omega^2 \begin{bmatrix}
\rho_x & 0 \\
0 & \rho_y
\end{bmatrix}
\begin{bmatrix}
u_x \\
u_y
\end{bmatrix}
\]

(2)

Figure 2 shows the band diagrams of the model cell as well as the retrieved effective stiffness and inertial density. Both anisotropic stiffness and density of the metasolid can be observed in re-
gions above the low-frequency resonance gap. Results demonstrate clearly that the gap-related modulation that arises from the added inclusion plays a vital role in the transition from isotropic density of the host lattice to the anisotropic density. The anisotropic density achieved here is nearly dispersionless in the frequency range ~2.0-6.0 kHz, which corresponds well to the recovered linear dispersion regime in band diagrams.

Figure 1: The schematics of the proposed dual-anisotropic metasolid.

Figure 2: Band structures and effective medium parameters of the metasolid with and without the inclusion.

3. Conclusion

We have presented a new type of solid metamaterials with simultaneous anisotropic stiffness and inertial density. The obtained dual anisotropy is nearly dispersionless in a broad frequency range, making the metasolid superior than previous models. All these findings have been verified through band-structure and effective-medium analyses. Our studies are expected to advance the progress of acoustic and elastic wave controlling with sound applications to cloaking and shock mitigation.

REFERENCES


