Mechanical behaviour of a model random fiber network under harmonic small strain

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Abstract

Fibrous materials, such as mineral wool, are widely used for acoustic insulation in various construction applications, including partitions, ceilings, and more. Mineral wool consists of a random network of glass fibers that are partially bound by polymeric bonds. However, the relationship between its microstructure and its acoustic behavior remains poorly understood. Historically, studies of macroscopic acoustic parameters have assumed that the fiber network behaves as a rigid skeleton. This assumption, though convenient, proves inadequate for modeling applications like floating floors or ceilings, where the displacement of the material's structure plays a significant role. Consequently, the primary objective of this research is to investigate the dynamic behavior of mineral wool and establish connections between its microstructure and its macroscopic mechanical properties.
To achieve this, a series of 54 model specimens were created to systematically examine how various microstructural parameters influence the material's behavior. Macroscopic measurements, focusing on quasi-static quantities such as stiffness and loss factor under small strain conditions, were conducted. These measurements revealed that certain microstructural characteristics significantly impact the dynamic performance of the material. Building on these observations, a simplified analytical model was developed based on existing research. This model successfully replicated the trends observed during the measurements and identified the predominant mechanisms of energy dissipation in the material.

However, the analytical model demonstrated limitations, particularly for specimens with a higher volume fraction of polymer binder. To better understand this discrepancy, confocal microscopy was employed to examine the material's microstructure. The images revealed that the polymer binder is distributed very irregularly throughout the material. Moreover, the structural complexity of the material was found to be far greater than initially assumed. Additional mesoscopic observations and preliminary experiments highlighted a critical property of the material: it exhibits significant anisotropy, even at small scales. Specifically,

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the compressive stiffness across the material's thickness is relatively low, while distinct fiber sheets are observed in the transverse direction. This anisotropic structure raises important questions about its influence on the material's overall behavior, particularly in light of the experimental findings, and these considerations are explored in depth.

Finally, the study outlines several promising avenues for further research, which build on the insights gained from this work.