Controlled distributed damage phenomenon in architectured lattice materials.

Michael Ryvkin[*1]

[1]School of Mechanical Engineering, Tel Aviv University – Israel

Abstract

An effective strategy observed in nature for resisting external destructive forces is to avoid localized catastrophic failure by damage of distributed sacrificial elements. This phenomenon significantly contributes to the remarkable mechanical properties of many biological materials.

By absorbing energy under extreme loading conditions, these materials can undergo substantial deformations while remaining intact. A specific composite material microstructure can achieve this effect by incorporating distributed weak bonds that fail first. They are found, for example, in the organic adhesive holding together nacre tablets and in bone collagen tissue. Beyond bimaterial composites, the sought microstructure can also be generated by the specific shape voids in solid parent material. The periodic two-dimensional architected lattice cellular materials that realize this opportunity are the subject of the present communication. Their controlled quasi-static brittle failure behavior is considered by modeling the microstructure as a network of Euler-Bernoulli beam elements (links) rigidly connected at the nodal points (1-3).

For the study of the damage propagation dynamics, the model with massless links and point masses at the nodal points is applied. The problems of impulse and step-function loadings applied to the straight linear lattice boundary are considered. As a result of the failure of periodically located separated sacrificial links, the initial lattice material tranforms to a new one with reduced stiffness, and the phase transition takes place. Two waves types are observed: sacrificial elements failure wave and leading elastic wave propagating in front of it in the undamaged lattice. Consequently, the elastic wave velocity exceeds that of the damage front. Due to the breakage of sacrificial elements, the internal force's amplitude in the leading wave is significantly lower than the applied force's magnitude. The high frequency vibrations caused by the breakage of sacrificial elements are localized within the damaged layer and do not affect the leading wave. In practice, the vibration energy finally goes to heat due to the nonlinearity

---

[*] Speaker

of a natural parent material. It is found that the increase of the applied force raises both the damage wave velocity and the leading wave amplitude. However, the amplitude variation is notable only for small applied force values near the fracture initiation limit. The thickness of the partly damaged material layer can far exceed that of the fully damaged layer in lattice materials of the same relative density, which lack a specific architecture with sacrificial bonds. Therefore, for the optimal parameters combination, the sacrificial bonds layout can not only preserve the specimen shape after unloading but also provide outstanding energy absorption properties.

References:

(1) Cherkaev, A and Ryvkin, M. Damage propagation in 2D beam lattices: 2. Design of an isotropic fault-tolerant lattice, Archive of Applied Mechanics , 89, 503-519, 2019.
(2) Ryvkin, M., Slesarenko, V., Cherkaev, A., Rudykh, S. (2019). Fault-tolerant elastic-plastic lattice material. Philosophical Transactions of the Royal Society, Series A, 378, Article 20190107.
(3) Bolshak, G. and Ryvkin, M. Bio-inspired beam lattice materials with sacrificial bonds. International Journal of Engineering Science 193 (2023) 103938.