Nano-honeycomb structures for optimal energy absorption: numerical analysis and experiments.

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Significant progress has been made over the past years in order to better understanding of the materials used in nanoscience and nanotechnology. In addition, due to the development in additive manufacturing [1] and laser lithography, based on the photon polymerization of a variety of UV-curable photoresist [2,3] it is now possible to manufacture of almost any type of nano-structural configuration, of almost any relative density, and at almost any length scale above a few nanometers.

Beside of that, among all prismatic shapes, the honeycomb architectures are the most well-established cellular designs [4-6]. By looking to wildlife, we observe the deployment of the honeycomb patterns in various structures such as corks, bones of birds, and beehives. Inspired by nature, the low density honeycomb structures employed in industrial applications (such as automobile and aerospace sectors as well as personnel protection and protective packaging applications) have been traditionally made with hexagonal formations. The high degree anisotropy of three dimensional honeycomb structures makes them well-suited for mechanical applications where weight specific performance matters and where the primary loading direction is a priori known.

The prismatic structures also have the reputation of exhibiting exceptional impact energy absorption properties. The design space thereby exceeds by far the limits of seminal works on thin-walled honeycombs made from metallic foil. An extensive computational and experimental study is performed on the large strain out-of-plane compression response of honeycombs covering different distinct structural configurations and relative densities. In order to develop a new class of stable metamaterials providing exceptionally high specific impact energy absorption capabilities and with the assistance of nanoscience and nanotechnology, we characterize the large strain compression response of honeycomb metamaterials with e.g. square, circular und hexagonal in-plane topology through experimental and finite element simulation approaches. The results of this work will be instrumental in choosing the optimal relative density and topology of honeycombs in targeted applications at the nanoscale.

For performing the mechanical compression on nano-scale structures, we designed and fabricated an in-house miniature compression device to load the specimens under the static loading conditions all the way to fracture. The experiments are performed in the Scanning Electron Microscope (SEM) in order to observe the nanostructures deformations and record the clamps displacements. The planar Digital image Correlation (DIC) system is also used in an incremental correlation model to obtain displacements. In addition, the evolution of the effective von Mises strain fields within the specimen gage sections is also determined through planar DIC. Interestingly, we discovered different buckling modes in different cellular nano-structures. It is worth mentioning that optimal honeycomb structures for high energy absorption should not buckle and respond through the formation of folds.

Therefore, we strongly advocate taking into account the knowledge of the nanoscience and nanotechnology to expand the understanding of nanostructures in the energy storage sectors; it leads to new development of energy absorption applications. The nanotechnology and nanostructures are now playing a significant role in scientific development and are impacting more people with higher quality products.

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