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Graphene oxide based functional hierarchical materials

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ABSTRACT

Current synthetic composite structural materials typically exhibit a trade-off between mechanical properties, sacrificing one property for the enhancement of another. Comparatively, natural materials have been shown to optimize several properties simultaneously. The origin of this remarkable capacity is believed to be in large part due to the hierarchical structure observed in natural materials that span length scales over several orders of magnitude. Limitations in currently available processing methods and materials have restricted the ability to reproducibly and cost-effectively manufacture hierarchical, biomimetic materials. However, graphene oxide (GO) has proven to be an excellent candidate for the facile fabrication of such materials. In earlier studies, we have demonstrated four levels of the hierarchical structure of GO papers formed by vacuum filtration of aqueous GO dispersions – the nanometer thick graphene oxide sheets, ~75-nm thick lamellae of stacked nanosheets, ~400-nm thick superlamellae, and finally the paper itself on the micron scale. By incorporating various polymer materials into the GO papers with controlled ordering, we are able to tune the interactions of the intermediate length scale structures. The ability to fuse GO papers further allows for the creation of novel materials where properties vary in the direction of stacking. In addition, these materials can be rendered multifunctional, by means of postprocessing, to induce properties such as electrical conductivity. In this study, we provide an overview of this design process and demonstrate a system that replicates the structure of fish armor plating while adding electrical functionality. Earlier studies on the organization of fish armor plating reveal the complex structure of the individual scales, where each individual layer serves a discrete function in resisting puncture attacks to the fish. The uppermost layer, for example, would be of maximum stiffness to prevent penetration, whereas the underlying layers are more compliant, serving to dissipate energy. This example is one a realization of a toolbox for the fabrication of complex hierarchical structures with the ability to control mechanical, electrical, thermal, and transport properties.