

Multiscale Engineering of Graphene Nanocomposites for High-Strain-Rate Energy Absorption and Impact Protection

Mohammed Majdoub, Dineshkumar Sengotuvellu, Sasan Nouranian, Ahmed Al-Ostaz
Center for Graphene Research and Innovation, University of Mississippi, MS 38677, United States
mmajdoub@olemiss.edu

Abstract

Achieving simultaneous improvements in stiffness, toughness, and energy absorption in graphene-polymer nanocomposites under high-strain rates remains a critical challenge. In this work, we demonstrate a multiscale design strategy to engineer high-performance graphene-polymer systems by integrating nanoscale interfacial chemistry with macroscale architectural control. At the nanoscale, graphene nanoplatelets (GNP) were chemically functionalized using aminopropyl isobutyl polyhedral oligomeric silsesquioxane (POSS) via a facile ultrasonication-assisted approach, enabling strong covalent and noncovalent interactions with polymer matrices. When incorporated into polyurea (PU), these GNP-POSS nanofillers promote enhanced dispersion and interfacial adhesion, resulting in simultaneous improvements in Young's modulus (up to 617 MPa), tensile strength (up to 25.1 MPa), and toughness (up to 125% increase), while preserving ductility. High-strain-rate testing using a split-Hopkinson pressure bar (SHPB) further reveals significant enhancements in plateau strength and energy absorption, highlighting the role of interface engineering in mitigating strain localization under dynamic loading. At the macroscale, multilayer polymer systems (MLPS) based on acrylonitrile butadiene styrene (ABS) reinforced with GNPs were designed to exploit architectural energy dissipation mechanisms. By tuning GNP content and stacking sequence, an optimal configuration containing 10 wt.% GNP exhibited a specific energy absorption of $\sim 92 \text{ kJ kg}^{-1}$ at 4000 s^{-1} , representing a ~ 1.5 -fold improvement over neat ABS and a substantial increase relative to lower strain rates. The enhanced performance is attributed to efficient stress delocalization, interfacial load transfer, and progressive layer engagement during dynamic compression, while excessive filler loading (20 wt.%) leads to agglomeration-induced performance degradation. Overall, this study establishes that high-strain-rate energy absorption in graphene-polymer nanocomposites can be systematically tailored across length scales, where interfacial chemistry governs nanoscale load transfer and multilayer architecture enables controlled macroscopic energy dissipation. These findings provide a unified framework for the rational design of next-generation lightweight materials for impact and impact protection applications [1].

Reference

- [1] Mohammad Mansourian-Tabaei, Mohammed Majdoub, Dineshkumar Sengottuvelu, Damian L Stoddard, Rooban VKG Thirumalai, Mine G Ucak-Astarlioglu, Ahmed Al-Ostaz, Sasan Nouranian. *ACS Appl. Mater. Interfaces* 2024, 16, 15, 19625–19641.

Figure

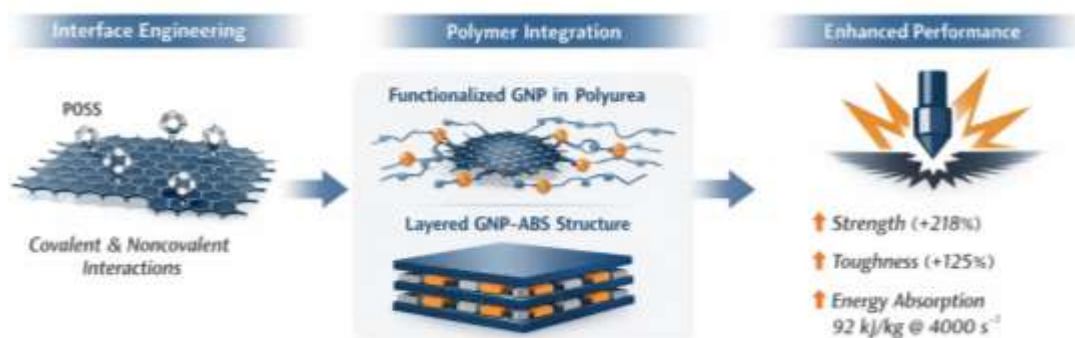


Figure 1: Bridging nanoscale interface engineering and macroscale architecture to enable high-strain-rate energy absorption in graphene-PU/ABS nanocomposites