uniformly dispersing short cylindrical micelles of a low-molecular-weight poly(ethylene oxide)-*b*-poly(butylene oxide) (PEO-PBO) diblock in commercial high-molecular-weight glassy PLLA. Introduction of these micelles into the PLLA results in a greater than tenfold increase in tensile toughness and notched Izod impact strength.

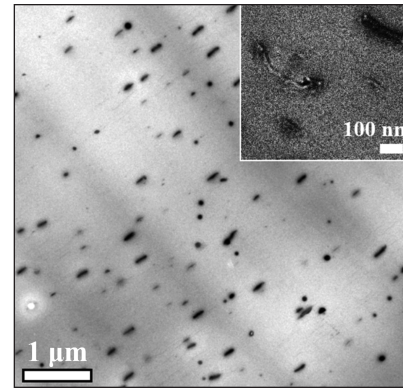
"Despite standard polymer physics, the attempt was to try and toughen PLA by creating the same type of nanoscale micelles that the group has been investigating for years in epoxy resins. This finding has the potential to be a facile and economical way to toughen PLA and perhaps produce low-density porous films," says chief scientist Frank Bates.

As reported in a recent issue of *ACS Macro Letters* (doi:10.1021/acsmacrolett.6b00063), Tuoqi Li, a graduate student in the group, synthesized a series of PEO-PBO diblock copolymers (a polymer with distinct blocks of monomers PEO and PBO grafted together to form a single copolymer chain), identified as EB1–3, as well as a PLLA-PBO diblock, identified as LB, by anionic polymerization with fixed composition but with varying total molecular weight. Blends of PLLA and both the diblock PLLA copolymers were then prepared by solvent and melt blending routes, followed by rapid cooling and aging for two days prior to characterization.

The resulting blend, identified as EB1/PLLA, showed a dispersion of the EB1 copolymer into small micelle-like particles as shown in the figure. In general, increasing the overall molecular weight of the EB additives in PLLA led to coarser dispersions and larger domain sizes than those expected from the assembly of individual micelles. The blend prepared using EB1 exhibited the greatest improvement relative to neat PLLA with a 1300% increase in tensile toughness and a 2500% increase in strain at break. By adding 1.25 wt% and 5 wt% EB1 to the PLLA, the notched Izod impact strength (measured by impacting the specimen by an arm from a height, and measuring the amount of energy absorbed by the sample) could be improved by 600% and 1500%, respectively.

"This is an exciting advance by Bates and co-workers that shows how diblock polyether additives can have a profound influence on toughness and impact strength without degrading other properties," explains Geoffrey Coates, an expert in defined structure polymers from Cornell University. He further says, "These additives have great potential to create poly(lactides) that have performance characteristics that match their already impressive environmental attributes."

The favorable enthalpic dispersion of EB1 into bulk PLLA as a micelle microstructure was attributed to a negative Flory–Huggins interaction parameter, which means that the mixing is of an exothermic nature. Study of the tensile specimens before and after deformation suggested that the improved performance derives from the formation of micron and submicron holes, which are caused by cavitation of the rubbery core micelles. Along with this kind of cavitation, micromechanical mechanisms of crazing and shear yielding are believed to produce a synergistic toughening effect in the PLLA-EB1 blends.



Transmission electron microscope image of 5 wt% EB/PLLA blend showing, in the inset, the micelle structure at a higher magnification. Credit: *ACS Macro Letters*.

This work represents a significant step toward developing a low-cost approach for toughening sustainable glassy PLLA materials based on a facile processing route. The controlled cavitation and void formation observed offers a new method for producing low-density porous materials with a host of potential applications. Future research would entail a more comprehensive study of the toughening mechanisms for the series of EB diblocks.

Rachana Acharya

Energy Focus

Carbon nanotubes improve radiation resistance of aluminum

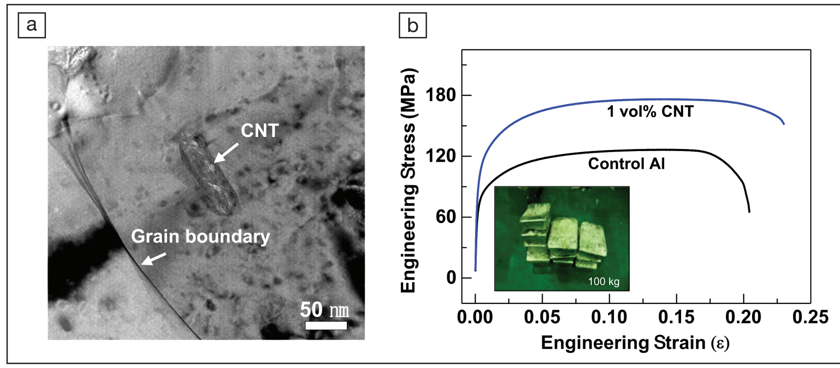
The limited operating lifetimes of nuclear structural materials is due to embrittlement and porosity that occur in these materials under long-term radiation exposure near a reactor core. Carbon nanotube (CNT)-reinforced aluminum composite materials provide a possible solution to this problem. The addition of small quantities of CNTs to aluminum dramatically improves the material's irradiation tolerance, suggesting potential applications in nuclear reactors, nuclear waste containers, nuclear batteries, and spacecraft. The dispersion of multiwalled carbon nanotubes in a metal matrix effectively mitigates radiation damage through additional internal interfaces for self-healing of radiation defects, and improves the mechanical properties by inhibiting dislocation propagation.

In a recent issue of *Nano Energy* (doi:10.1016/j.nanoen.2016.01.019), a research team led by Ju Li from the Departments of Nuclear Science Engineering and of Materials Science Engineering at the Massachusetts Institute of Technology investigated the basic materials science of an aluminum/CNT composite. "The key technology of our research is the dispersion of the CNTs inside metal grains," says Kang Pyo So, the lead author of this work. These CNTs facilitate the recombination of atomic-level defects, such as vacancies, interstitials, and dislocation loops, and may provide pathways for releasing helium instead of trapping helium along grain boundaries to cause embrittlement. CNTs transform

https://doi.org/10.1557/mrs.2016.102 Published online by Cambridge University Press

to aluminum carbide when radiated to a high dose of 72 dpa, but the one-dimensional nanomorphologies survive along with the self-healing interfaces that catalyze defect recombination.

In addition, this composite material exhibits improved mechanical strength and toughness as compared to the reference metal. The high-aspect ratio of CNTs creates obstacles for dislocation and crack propagation in the metal matrix. The standard tensile test of aluminum with 1% volume CNTs shows significant improvement in tensile strength without decreasing ductility as compared to the bulk Al specimen. The manufacturing process is also scalable. At less than two times the price of aluminum alloys, the team mass-produced over 100 kg of this composite material in the laboratory. "We can use this nanocomposite as a lightweight and long-term sustainable material in automotive vehicles, airplanes, and ships," Kang Pyo says.



Dispersion of carbon nanotubes (CNTs) inside Al grain improves tensile strength without sacrificing ductility, where (a) shows a transmission electron micrograph of the CNT inside an Al grain and (b) shows the stress–strain curve (inset: 100 kg of the Al+CNT composite). Credit: *Nano Energy.*

"This work provides an insight to explore a new regime for designing materials under radiation applications, from previous approaches such as dispersing oxide nanoparticles into an Al matrix," says Shimin Mao, an expert studying irradiation effects of materials at the University of Illinois at Urbana-Champaign. "This will encourage other researchers in the field to implement more fundamental studies on nanocomposite-type radiation resistance materials."

YuHao Liu

https://doi.org/10.1557/mrs.2016.102 Published online by Cambridge University Press