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Nanotribological Properties of Chemically Modified Graphene

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Atomically thin graphene is the ideal model system for studying nanoscale friction due to its intrinsic two-dimensional anisotropy. Furthermore, modulating its tribological properties could be an important milestone for graphene-based micro and nano-mechanical devices. Here, we report that the tribological properties can be easily altered via simple chemical modifications of the graphene surface. Friction force microscopy measurements show that hydrogenated, fluorinated, and oxidized graphenes exhibit, 2-, 6-, and 7-fold enhanced nanoscale friction on their surfaces, respectively, compared to pristine graphene. The measured nanoscale friction should be associated with the adhesive and elastic properties of the chemically modified graphenes. Density functional theory calculations suggest that, while the adhesive properties of chemically modified graphenes are marginally reduced down to ～30%, the out-of-plane elastic properties are drastically increased up to 800%. Based on these findings, we propose that nanoscale friction on graphene surfaces is characteristically different from that on conventional solid surfaces; stiffer graphene exhibits higher friction, whereas a stiffer three-dimensional solid generally exhibits lower friction. The unusual friction mechanics of graphene is attributed to the intrinsic mechanical anisotropy of graphene, which is inherently stiff in plane, but remarkably flexible out of plane. The out-of-plane flexibility can be modulated up to an order of magnitude by chemical treatmentof the graphene surface. The correlation between the measured nanoscale friction and the calculated out-of-plane flexibility suggests that the frictional energy in graphene is mainly dissipated through the out-of-plane vibrations, or the flexural phonons of graphene.

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