Fundamental Properties of Carbon Onions Correlated with Tribological Performance

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Abstract— A fundamental characterization of carbon onion films is performed using high-resolution transmission electron miscoscopy and electron energy loss spectroscopy for strucutres, scanning electron microscopy for film stalbility and force volume imaging by atomic force msicoscopy for mechanical perperties. The results are correlated with actual tribiolgical performance of carbon onion films in air and vacuum environments. We find that carbon onoin films show great promise as a nano-property enabled solid lubricant.

Multi-shell fullerenes, or carbon onions, are under investigation as a nano-property enabled solid lubricant. The potential applications for a carbon onion-based lubricant range from an environmentally benign option for wind power to a vacuum lubricant for solar panel deployment in space. These uses of carbon onions depend on both their individual properties such as mechanical strength and elasticity, and their interaction properties with a wear surface and with each other. When carbon onions are applied as a thin lubricating film, their stiction, rolling, and sliding interactions, with each other and with the wear surfaces govern their ultimate usefulness, in addition to their individual mechanical load-bearing characteristics.

Carbon onion physical structures are known to vary with synthesis temperature. Several authors have reported the structural evolution from spherical to polyhedral multi-shells as a function of increasing synthesis temperature [1]. It has been generally assumed that the structural evolution is accompanied by a change in the sp^3/sp^2 ratio, since a reduction in potential sp^3 defect sites, which are visible as broken shells in high-resolution electron microscopy (HRTEM) images, is observed. However, broken shells may also terminate in amorphous carbon networks that are more sp^2 than sp^3, and individual sp^3 point defects could be very hard to detect based on HRTEM images alone. Accurate knowledge of a systematic evolution of the sp^3/sp^2 ratio is important for the synthesis of carbon onions for an optimum lubricating film, especially at the nano-scale, since sp^2 carbons interact principally through π-electron overlap, while sp^3 defect sites exhibit local dangling bonds.

In this work, we investigate the fundamental tribological (frictional) and stability characteristics of the carbon onions in air and vacuum due to their distinctive structure (Figure 1 a and b) and frictional performance in different surroundings. HRTEM is used to investigate structural evolution from spherical to polyhedral multi-shells as a function of increasing synthesis temperature. Electron energy loss spectroscopy (EELS) is used to quantitatively investigate the sp^3/sp^2 ratio [2 MRS]. EELS is also used along with energy filtered TEM (EFTEM) to investigate the possible development of oxygen functionalities at defect sites during wear. Scanning electron microscopy is used to characterize film uniformity and force volume imaging by atomic force microscopy is used to provide information about film mechanical properties. The fundamental properties are correlated with tribological results obtained by ball-on-disk measurements [3, 4].

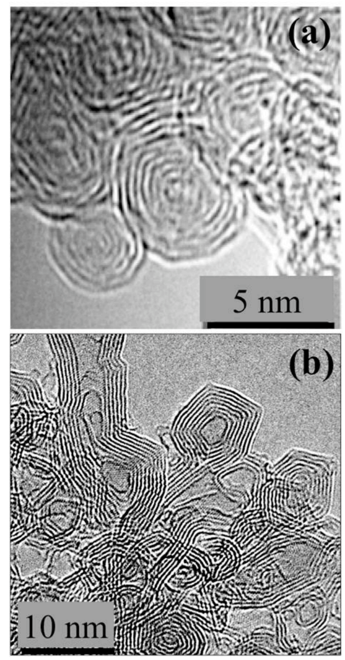

Figure 1. HRTEM images of carbon onions prepared by heat treatment of nano-crystalline diamonds at (a) 1700^{O}C and (b) 2300^{O}C.

The fundamental characteristics and performance of the additional nano-carbons, C_{60} and single-walled carbon nanotubes are also considered. We find that carbon onions may exhibit a combination of electronic and mechanical properties that result in the optimum tribological performance and film stability.

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