ENERGY TECHNOLOGY**DIVISION****ET****Tribology and Coatings**

The future use of fuel-efficient, low-emission, advanced transportation systems (for example, those using low-heat-rejection diesel engines or advanced gas turbines) presents new challenges to tribologists and materials scientists. High service temperatures, corrosive environments, and extreme contact pressures are among the concerns that make necessary new tribological designs, novel materials, and effective lubrication concepts. Argonne is working on methods to reduce friction, wear and corrosion, such as soft metal coatings on ceramics, layered compounds, diamond coatings, and hard surfaces.

Diamond and Diamondlike Carbon

Argonne is working on methods to produce crystalline cubic diamond coatings, as well as various types of amorphous carbon coatings. *Science* magazine has elected diamond as "Molecule of the Year" because the hardness and room-temperature thermal conductivity of diamond is superior to that of any other substance known. Considerable progress has been made in understanding the electronic, optical, and microstructural properties of diamond and diamondlike carbon films. Results of engineering testing are also beginning to emerge.

It is important to note that several different types of hard carbon can be produced as thin coatings. Cubic diamond with sp^3 bonding can be produced by plasma-assisted CVD. High substrate temperatures (800-1000°C) are generally required for diamond growth; thus, limiting the choice of substrate materials. Films tend to be rough on a microscopic scale. Argonne is working on methods to deposit smooth diamond. More testing is needed to determine the best form of carbon and deposition method for specific engineering applications. Results of tribological testing of diamond films produced by hot-filament CVD and microwave-enhanced CVD have reported friction coefficients of 0.04 against steel and 0.01-0.24 against brass.

In contrast, diamondlike carbon (DLC) is a form of amorphous carbon in which the atoms have a

random arrangement. Many times harder than steel, DLCs resist wear and offer low friction when sliding against many materials, and seem to be extraordinarily inert. These DLC coatings are produced at low temperatures (near room temperature), eliminating the risk of damage to heat-sensitive parts. Depending on the particular process used, DLC can be either a good or poor electrical insulator. Coating thicknesses are less than 1 micrometer (0.000 040"), eliminating the need for regrind of precision parts.

Hydrogen-free DLC is amorphous has a density and hardness approaching diamond, but is not as well understood. The first DLC films were produced at room temperature more than 20 years ago using ion beam deposition. Other more inexpensive methods of producing hydrogen free DLC can be used, include sputtering and evaporation, and Argonne is working on these methods.

Hydrogenated DLCs (also known as diamondlike hydrocarbons) are produced in plasma processes where much hydrogen is present and where conditions are not suitable for true diamond formation. Recently, considerable progress been made in producing these films economically by means of sputtering [1], arc-discharge [2], and low-energy ion beam deposition [3, 4]. This latter process is being explored at Argonne. Films produced by these methods tend to be softer than films containing no hydrogen, but there is some

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indication that the tribological properties are better.

No clear picture has emerged as to the best form of carbon, or deposition method, for coatings. IBD α -C films produced using low-energy beams of C atoms exhibited hardness and density similar to that of diamond; the coefficient of friction against steel was 0.15 [5]. Ion energies of 10 eV to 2 keV were used for the C deposition. In contrast, films produced using low-energy beams of hydrocarbons are softer [6].

There is interest in DLC coatings deposited on ceramics. Ceramics offer chemical inertness, hardness, and strength, but often suffer from poor tribological performance. If DLC films can be successfully applied to the sliding surfaces of ceramics, the favorable mechanical properties of the ceramic (strength and stiffness) will be retained along with the good tribological properties of the DLC film. In one example, DLC films were produced using 400-eV CH_4 ions. A description of the process and a report of the tribological behavior of the resulting films can be found in Ref. [4]. Tribological properties of other DLC films have been reported [4, 7-12].

There are many potential uses for DLCs which include

1. wear reduction in valve guides/stems
2. piston ring/bore coating to decrease wear and oil consumption
3. gear and bearing coating to increase durability and load capacities (including journal bearings)
4. fuel-injector parts to reduce wear when used with alternative fuels
5. improvements in rolling-contact-fatigue life of cams and cam-roller followers
6. coatings for orthopedic use
7. increasing abrasion resistance of vanes in gas turbines and/or turbochargers
8. thermal management
9. corrosion-resistant coatings

Other applications include protective coatings for optical components, coatings for orthopedic

use, thermal management, and sensors.

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