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Tribological properties of ultra nanocrystalline diamond film-effect of sliding counterbodies

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ABSTRACT

We report role of sliding counterbodies which change the friction and wear properties of ultra nanocrystalline diamond (UNCD) film. Interestingly, SiC ball shows high value of friction coefficient ~0.4 while low and ultra low values of friction coefficient are obtained using non carbon based ceramics and metallic counterbodies. Deviation in friction coefficient while changing the counterbodies is correlated to the contact adhesion of sliding interface. Origin of increased value of friction coefficient of UNCD films sliding against SiC ball is attributed to the presence of dangling covalent σ bonds of carbon atoms which possibly increase the adhesive force in the sliding plane.

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1. Introduction

Carbon based systems comprise an impressively broad and continually expanding class of engineering materials that range from the building blocks of biology to carbon allotropes with extreme and exotic properties [1–3]. In certain conditions, the use of liquid lubricants as friction and wear retardant agents in contact sliding surfaces are often technically inefficient and materially unsuitable. Instead, formation of solid lamellar lubricants at the interface allows smooth sliding with low coefficient of friction and high wear resistance [4–6]. For this purpose, diamond is known to be one of stiffest and hardest material having high elastic modulus, high fracture toughness, high thermal conductivity, low thermal expansion coefficient and chemical inertness. This superhard materials offer broad optical transparency high refractive index, wide band gap and low or negative electron affinity. These exceptional qualities make diamond an ideal candidate material for numerous industrial applications other than tribology [7–9]. Some of these above mentioned factors result in low friction and wear under contact sliding conditions. Intrinsically, magnitude of friction and wear of diamond are influenced by several factors such as hardness, elastic modulus, fracture toughness, thermal conductivity, sp^3/sp^2 hybridization ratio, crystallite size and quantity of hydrogen present in these coatings [10–12]. Extrinsically, friction of natural and CVD diamond is highly dependent on the environmental test atmosphere. It is well established that the friction coefficient varies by an order of magnitude, decreasing from a value of approximately 1 under UHV conditions to between 0.05 and 0.15 in air [11]. Under high vacuum and in inert atmosphere such as argon and nitrogen, the dangling bonds are free to interact between each other which are known to increase the adhesive component of friction. The low macroscopic friction of diamond in air has been attributed to the passivation of the surface by –H and –OH groups and/or by the production of lubricious sp^2 bonded species [13,14]. Other factors which influence the friction are film thickness, substrate roughness, surface orientation and sliding direction [15,16]. The effect of sliding bodies on the dissipation of friction in diamond surface is discussed in terms of mechanical and chemical behavior of surfaces and nature of adhesion with counterbodies [17]. But, to our knowledge, no detail analysis of chemical and deformation behavior of UNCD film sliding with various balls has been presented so far to enable a comprehensive understanding of friction and wear.

The motivation behind the present paper is to study the tribological behavior of nanocrystalline diamond film sliding with various ceramic and metallic counterbodies. Chemical behavior and deformation of wear track with various counterbodies are studied by Raman spectroscopy operating in visible and ultraviolet wavelengths and FESEM, respectively. Influence of structural and morphological behavior of wear tracks of nanocrystalline diamond film and evolution of friction coefficient along with wear mechanism are reported in the present paper.

2. Experimental

UNCD/a-C composite films on silicon (111) were deposited using microwave plasma enhanced chemical vapor deposition (MWCVD) by a plasma medium containing 17% CH_4/N_2 mixture.

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The temperature of growth was kept at 600 °C and the working pressure was maintained at 22 mbar with an MW power of 800 W. Prior to deposition of films over a period of 390 min, the substrate were ultrasonically irradiated to remove the oxide layer and other contaminants. For this pre-treatment purpose, a mixture of ultradisperse diamond (UDD, mean grain size 3–5 nm) and nanocrystalline diamond (NCD, mean grain size 250 nm) powders suspended in 75 ml n-pentane was used. The samples under investigation were pre-treated in this suspension containing a fixed amount of NCD (50 mg), while the UDD amount was kept at 80 mg. Details of the film synthesis is presented elsewhere by Popov et al. [18]. The morphology of the film and wear tracks was investigated by cross-sectional and top-view field emission scanning electron microscopy (FESEM) images by LEO 435 VP microscope (Zeiss). Micro- Raman measurements were performed using a spectrometer to record the local chemical structure present in the film surface as well in the wear track. For this purpose, laser radiation with wavelengths of 325 nm and 514.5 nm (Renishaw inVia, in the backscattering configuration) was used as an excitation source at a laser power of 5 and 8 mW, respectively. Nanoindentation measurements (CSM Instruments, Switzerland) were performed with a diamond Berkovich indenter with a loading–unloading rate of 4 mN/min. This was performed up to a maximum load of 2 mN. Oliver and Phar method was used to calculate the elastic modulus and hardness of the film [19]. Hardness, elastic modulus and surface roughness of ball counterbodies are provided by the CSM Instruments, Switzerland. Linear reciprocating mode of a ball on disk micro-tribometer (CSM Instruments, Switzerland) was used to carry out tribological tests. The effect of ball on friction and wear was evaluated using various counterbodies such as SiC, Si_3N_4, 100Cr6 steel, ruby, 440C steel and Al_2O_3 balls. In each case, 6 mm diameter ball was used. Sliding speed and normal load were kept constant 2 cm/s and 1 N, respectively. A constant test stroke length of 3 mm was used. The total sliding distance covered for each measurement was 20 m. Surface roughness of wear track along the track length were measured using a Dektak 6M-stylus profiler (Veeco, USA). In this profiler diamond tip radius is 5 μm and the profiling was performed at a load of 5 mg with a scan length of 200 μm in ambient conditions. Measurement is done three times on each sample and data was found to be reproducible. Wear track dimensions were measured using a Dektak 6M-stylus profiler (Veeco, USA). Wear rate k is calculated from the relation of $k=V/(F\times S)$, here F, S and V are normal load, sliding distance and wear volume, respectively.

3. Results and discussion

3.1. Microstructure and morphology of UNCD film

A typical top-view and cross-sectional SEM images of the film are shown in Fig. 1(a) and (b), respectively. From these images, it can be seen that the growth of grains are initiated from individual nucleation sites in the form of nodules. When the amount of UDD is increased to a moderate level, the growth rate of these nodules increased and the number density was abundant to cause coalescence good enough for their continuous film. Number and size of voids, at the interface with silicon substrate, decreased with moderate amount (80 mg) of UDD powder used in the pre-treatment process. Higher and optimized amount of powder (UDD) reduces voids causing formation of dense and thick films. Thickness of the film is ∼820 nm as shown in cross section of SEM image. In turn, this microstructural densification process reduces film thickness and surface roughness with increase in hardness and elastic modulus of films to 41 GPa and 457 GPa, respectively.

3.2. Raman spectroscopy of pristine UNCD film

The Raman spectra were recorded on the film surface at an excitation wavelength of 325 nm and 514 nm as shown in Fig. 2(a) and (b), respectively. It is well known that as a consequence of resonance effects the Raman spectra of diamond films depend on the excitation wavelength. Total of three deconvoluted bands identified in the spectra. These are ascribed to different local structural units. The fundamental diamond line at 1332 cm^{-1} which should arise out of aforementioned resonance effects and small crystallite size, is not visible in these spectra. Graphite related D and G bands are observed at 1433 and 1663 cm^{-1}, respectively, while using 325 nm excitation sources. However, peak positions of D and G bands are found to

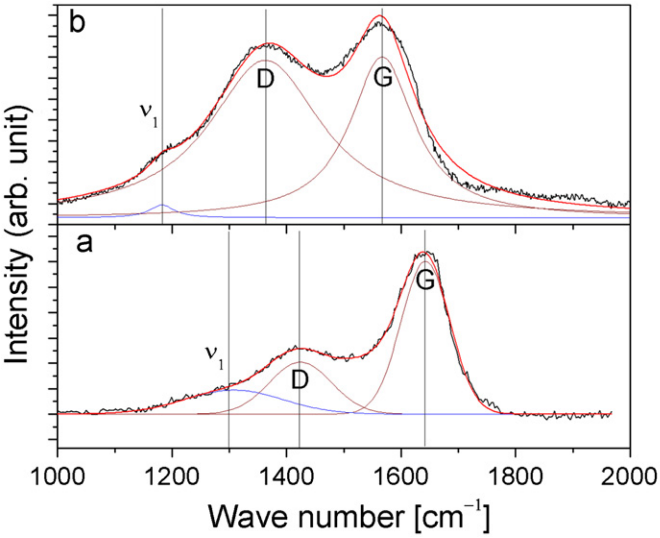

Fig. 2. Raman spectroscopy of UNCD film using (a) UV laser with 325 nm and (b) 514 nm wavelength.

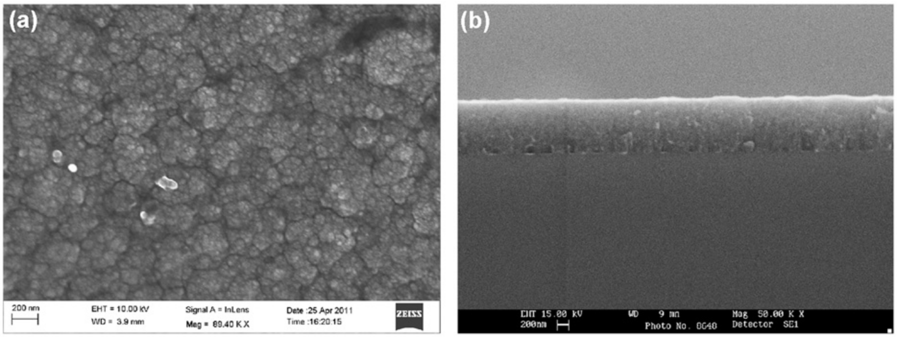

Fig. 1. Morphology of UNCD film (a) surface and (b) cross ection.

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