Comparison of the wear particle size distribution of different a-C coatings deposited by vacuum arc

Ying Ren[1]*, Ingo Erdmann[1], Victoria Khlopyanova[2], Friederike Deuerler[1], Volker Buck[2]
[1]Faculty D-Department of Mechanical Engineering, University of Wuppertal, 42119, Wuppertal, Germany

[2]Thin Film Technology Group, Faculty of Physics and CENIDE, University Duisburg-Essen, 47057, Duisburg, Germany

Abstract

For biomedical application in the field of artificial hip joints diamond-like carbon (DLC) coatings have been widely studied due to their excellent mechanical, tribological and biological properties. The wear particles as the main factor limiting the life expectancy of hip joints have attracted more and more interest, not only the number of them, but also the distribution of their size. In this study we have deposited DLC coatings on stainless steel (P2000) by a vacuum arc adjustable from anodic to cathodic operation mode. To improve the adhesion of the DLC coating on P2000, titanium as a metallic interlayer was deposited by cathodic vacuum arc evaporation. The frequency distribution of wear particles generated using a disc-on-disc test was measured by a particle size analyzer. It was shown that the maximum of the frequency distribution e.g. at —1000 V bias can be shifted to below 1 µm with increasing anode/cathode diameter ratio d_a/d_c.

1. 1.Introduction

Many methods have been developed for the deposition of DLC coatings in biomedical applications. In this study, the vacuum arc deposition which can be adjusted from anodic to cathodic operation mode was used to deposit the DLC coatings to be applied in artificial hip joints. What's more, different DLC coatings can be deposited by controlling the anode-cathode diameter ratio of d_a/d_c. The purpose of this study was to compare the wear particles size distribution of DLC coatings with different d_a/d_c, which was also important in the evaluation of life time of implants, not only the number of wear particles.

2. Materials and method

Discs as substrates with diameter of 31 mm and thickness of 4 mm, were made of stainless steel (P2000). Titanium was chosen as interface layer to improve the adhesion of the DLC film to P2000. The friction and wear tests were carried out using a disc-on-disc tribometer (Wazau TRM 1000) in deionized water as lubricant under a normal force of 120 N, and a sliding velocity of 0.01 m/s was chosen. After tribological tests, the wear particles generated were measured using the particle size analyzer Horiba LA-950 with 17 channels per decade. Due to the properties of coatings, the sliding time in these experiments was varied in order to get more wear particles.

3. Results

Here the volume density distribution $q_3(x)$ was chosen to characterize the size of particles, which represents the amount of particles of a given particle size x relative to the entire particles size distribution, as shown in Fig. 1.

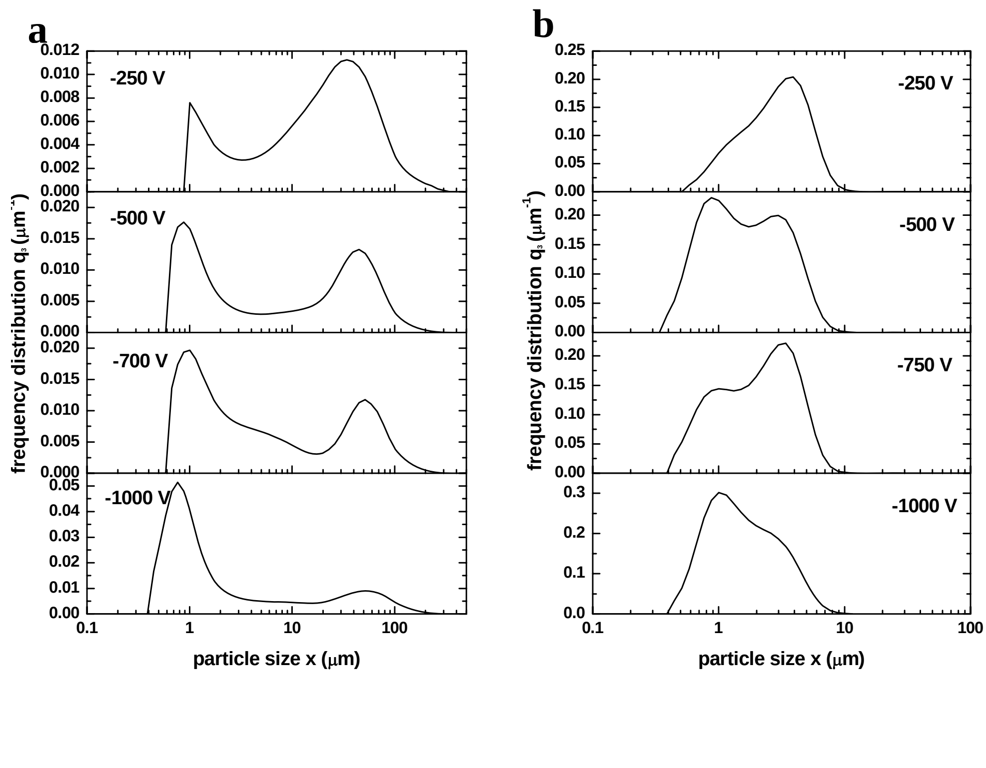

Fig. 1 Volume density distribution $q_3(x)$ at the DC bias from —250 V to —1000 V with the anode-cathode diameter ratio of (a) d_a/d_c = 3/1 and (b) d_a/d_c = 1/1

The modal value x_{mod}, the particle size at which the density distribution $q_3(x)$ exhibits a maximum, can be determined that characterize the particle collective from the measured size distribution $q_3(x)$. Fig. 1 (a) showed that when the DLC coatings were deposited with d_a/d_c = 3/1, the wear particles collected were in the range of 0.3 to 200 µm which was observably different from the DLC coatings with d_a/d_c = 1/1, 0.3 to 10 µm as shown in Fig. 1 (b).

However, there were two peaks in volume density distribution no matter which anode-cathode diameter was used. One peak was distributed at ~ 1 µm ($x1_{mod}$) for d_a/d_c = 3/1 and d_a/d_c = 1/1, another at ~ 50 µm ($x2_{mod}$) for d_a/d_c = 3/1 and ~ 5 µm for d_a/d_c = 1/1. That means that most particles were distributed in the range of smaller particles and larger particles. In Fig. 1 (a), it was found that two peak heights representing the density distribution of $x1_{mod}$ and $x2_{mod}$, $q(x1_{mod})$ and $q(x2_{mod})$, respectively changed with the bias. Fig. 1 (b) showed that the curve had the same tendency with the bias when the DLC coatings were deposited at d_a/d_c = 1/1, just the maximum of the curve was shifted from ~ 1 µm to ~ 5 µm when the bias was increased from —500 V to —750 V. According to the previous work, the concentration of wear particles at —1000 V with d_a/d_c = 1/1 was distributed more equally in a whole range.

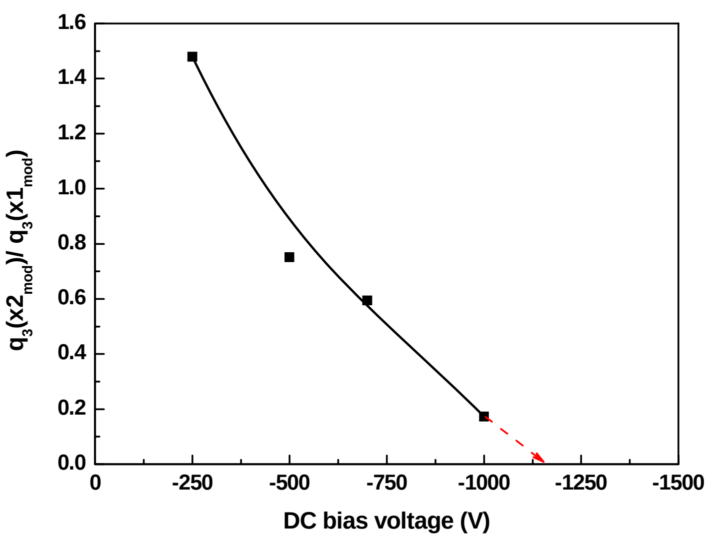

Fig. 2 Variation of $q_3(x2_{mod})/q_3(x1_{mod})$ ratio with DC bias voltage

The relative density distribution ratio of x2mod and x1mod is shown in Fig. 1. From Fig. 2 it is obvious that the ratio of $q_3(x2_{mod})$ and $q_3(x1_{mod})$ decreases from 1.5 to 0.15 regularly with increasing bias from —250 V to —1000 V; fitting with a curve of Bezier indicated that the maximum of the frequency distribution can be shifted to below 1 μm at higher bias. According to Bezier curve equation, one can try to get the approximation of bias at which the $q_3(x2_{mod})/q_3(x1_{mod})$ ratio eventually nears zero; from this extrapolation it can be expected that the wear particle size could be reduced and the frequency distribution would be downshifted to below 1 μm when the bias is slightly lower than —1100 V (see red line in Fig. 2).

4. Conclusion

Amorphous carbon (a-C) films were synthesized on P2000 substrates by vacuum arc technique using an anode-cathode diameter ration of d_a/d_c = 3/1 with the application of a DC bias to the substrate from —250 V to —1000 V. The influence of d_a/d_c and the substrate bias on the wear particle size distribution were investigated. When the films were deposited with d_a/d_c = 1/1, all particles generated were smaller than 10 μm. However, the wear particle size of a-C coatings deposited with d_a/d_c = 3/1 is distributed in the range of 0.3 to 200 μm. The maximum of the frequency distribution can be downshifted gradually with increasing bias to below 1 μm at voltages lower than —1000 V bias. It is estimated that all wear particles can be distributed in the range of ~ 1μm when the bias is slightly lower than approximately —1100 V.