Surface & Coatings Technology 204 (2009) 1040–1045

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Wear-resistant and low-friction diamond-like-carbon (DLC)-layers for industrial tribological applications under humid conditions

Wolfgang Tillmann *, Evelina Vogli [1], Fabian Hoffmann [1]

Technische Universität Dortmund, Institute of Material Engineering, Leonhard-Euler-Str. 2, 44227 Dortmund, Germany

A R T I C L E I N F O

Available online 11 June 2009

Keywords:
Diamond-like carbon (DLC)
Humid environment
Physical vapor deposition (PVD)
Wear
Friction
Multilayer

A B S T R A C T

Excellent wear and friction properties are important factors in almost all branches of industry. They increase the tool life just as affecting the power consumption, the surface finish of the workpiece and the production rate in a positive way. To facilitate higher productivity at lower operating cost, it is of particular importance to use tools with enhanced wear and friction attributes. Novel amorphous diamond-like-carbon (DLC) coated tools provide these properties in dry and even in humid environment which offers application possibilities in the wood machining industry.

The forestry, timber-, and paper-industry in Europe have a production value of approximately 400 billion Euros per year. For this reason, the supplying industry is very conscious to develop highly efficient tools. Especially wear and high friction of cutting tools are limiting factors in the processing of bulk wood.

This work is focused on the development of a DLC-system with high wear and friction resistance also under humid conditions which especially exist during the processing of bulk wood. Using the Physical Vapor Deposition (PVD)-process different DLC-coating systems have been deposited, in which the layer properties have been designed related to the humidity conditions. The layer properties and coating parameters have been systematically analyzed with special emphasis on tribological attributes. Tungsten carbide counterparts were used during wear and friction tests to analyse the tribological behaviour of the coatings. Furthermore Raman spectroscopy was applied to characterize the layers microstructure. Correlations between layer structure and corresponding wear and friction properties have been scrutinized.

1. Introduction

The requirements of tools for wood processing are constantly rising. The improvement of the material's wear resistance and frictional behaviour plays an important role to meet these demands. Several works have also dealt with the surface enhancement of wood machining tools. Beer et al. [1] examined wood cutting tools and deposited CrN and W–C:H-layers which doubled the tools life. Further studies [2,3] gave as well attention to hard coatings and nitriding the canter and peeling knives which resulted in an increase of service life by a factor of 5.

Diamond-like-carbon (DLC) coatings showed excellent tribological performance in a variety of employments, such as razor blades, hard disk drives, machining tools, pressing tools, automotive and aerospace parts [4–8]. Since the application range of DLC-coatings is enormous, researchers made big efforts to gain detailed information about the tribological behaviour under all kinds of environmental influence. DLC reacts particularly strongly with changing of humidity [9–12]. In addition to that, their properties also depend on the coating process and parameters. To understand the fundamental aspects of the influence of different pressures and atmospheres on wear and friction behaviour a lot of research work has been done [8,13–21]. Scrutinizing the mechanisms for the frictional behaviour of DLC-coatings Gao et al. [22] investigated the tribological behaviour of hydrogenated a-C:H-coatings in ultra high vacuum in order to eliminate oxygen and hydrogen as an interference factor. By controlling the addition and removal of the reactive gases and water vapour Gao et al. came to the conclusion that the interaction between the hydrogen at the surface and the added water change the surface structure of the DLC-coating which impacts negatively the frictional behaviour. Kim et al. [8] also discussed the a-C:H-layer's dependency on environmental influence and showed that coefficient of friction of hydrogenated DLC increases with increasing humidity while the friction coefficient of non-hydrogenated DLC decreases.

The aim of this present work is to develop and analyse DLC-coatings with good wear and friction behaviour under the humid environment which is needed for a good performance in wood machining tools.

2. Experimental

Three different non-hydrogenated multilayer DLC-coatings (a-C) were designed and manufactured by employing an industrial magnetron-sputter device (CemeCon MLsinox800, Germany) and compared with one hydrogenated (130 V Bias voltage) and one non-

* Corresponding author. Tel.: +49 231 755 2581; fax: +49 231 755 4079.
E-mail address: wolfgang.tillmann@udo.edu (W. Tillmann).
[1] Tel.: +49 231 755 2581; fax: +49 231 755 4079.

0257-8972/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.surfcoat.2009.06.005

Table 1
Coating process parameters and properties.

Number	Top layer	Bias voltage [−V]	Top layer thickness [μm]	Hardness [GPa]	Young's Modulus [MPa]	Friction coefficient μ	
						Dry	Humid
1	a-C:H	130	1.27	22.83 ± 0.57	205.37 ± 33.70	0.045	0.203
2	a-C	25	0.85	9.95 ± 1.17	83.77 ± 5.30	–	–
3	a-C	100	0.34	31.19 ± 0.89	221.34 ± 25.61	0.103	0.169
4	a-C	130	0.32	35.57 ± 0.84	249.63 ± 24.61	0.102	0.189
5	a-C	150	0.38	36.99 ± 1.25	258.52 ± 38.47	0.108	0.210

hydrogenated (25 V Bias voltage (see [12])) DLC-multilayer system. The composition and deposition time of the non-hydrogenated systems were kept constant, whereas the Bias voltage was changed within a range of 100 to 150 V. Process parameters and coating properties are listed in Table 1. The substrate material was a low alloy working steel (1.2235 German standard, 80CrV2), mostly applied for wood machining tools, which was cut into cylindrical specimens with a 40 mm diameter and a thickness of about 5 mm. Prior to the coating the samples were grinded, polished and ultrasonically cleaned. All targets had an area of 200 × 88 mm^2 and were bonded to a water-cooled backing plate. Argon and krypton were used as plasma gas in the coating chamber. Just before the coating in the evacuated chamber the surfaces of the substrates were etched. Therefore the plasma gas was ionized and accelerated onto the specimen for 60 min at a Bias voltage of − 650 V in order to remove contaminations and activate the surface. To enhance the adhesion between the DLC-layers and substrate, a CrN-bonding layer was deposited by sputtering two pulsed chromium targets in nitrogen atmosphere. A graded structure of the three layers between the CrN-bonding layer and the non-hydrogenated DLC top layer is responsible for achieving also a good cohesion.

The morphology of the DLC-coated specimen was analyzed by using a SEM (JEOL JXA 840, Japan), while structural analysis were performed employing a LabRam IM Raman-Spectrometer (Horiba Jobin Yvon, France) with a 533 nm Nd-Yag-Excimer-Laser. Utilizing a pin-on-disk tribometer (CSM, Switzerland) and an optical microscope (Zeiss Axiophot, Germany) wear tests and the evaluation of wear and friction coefficients were carried out. To investigate the influence of the humid environment on the wear resistance of the coating the pin-on-disk-

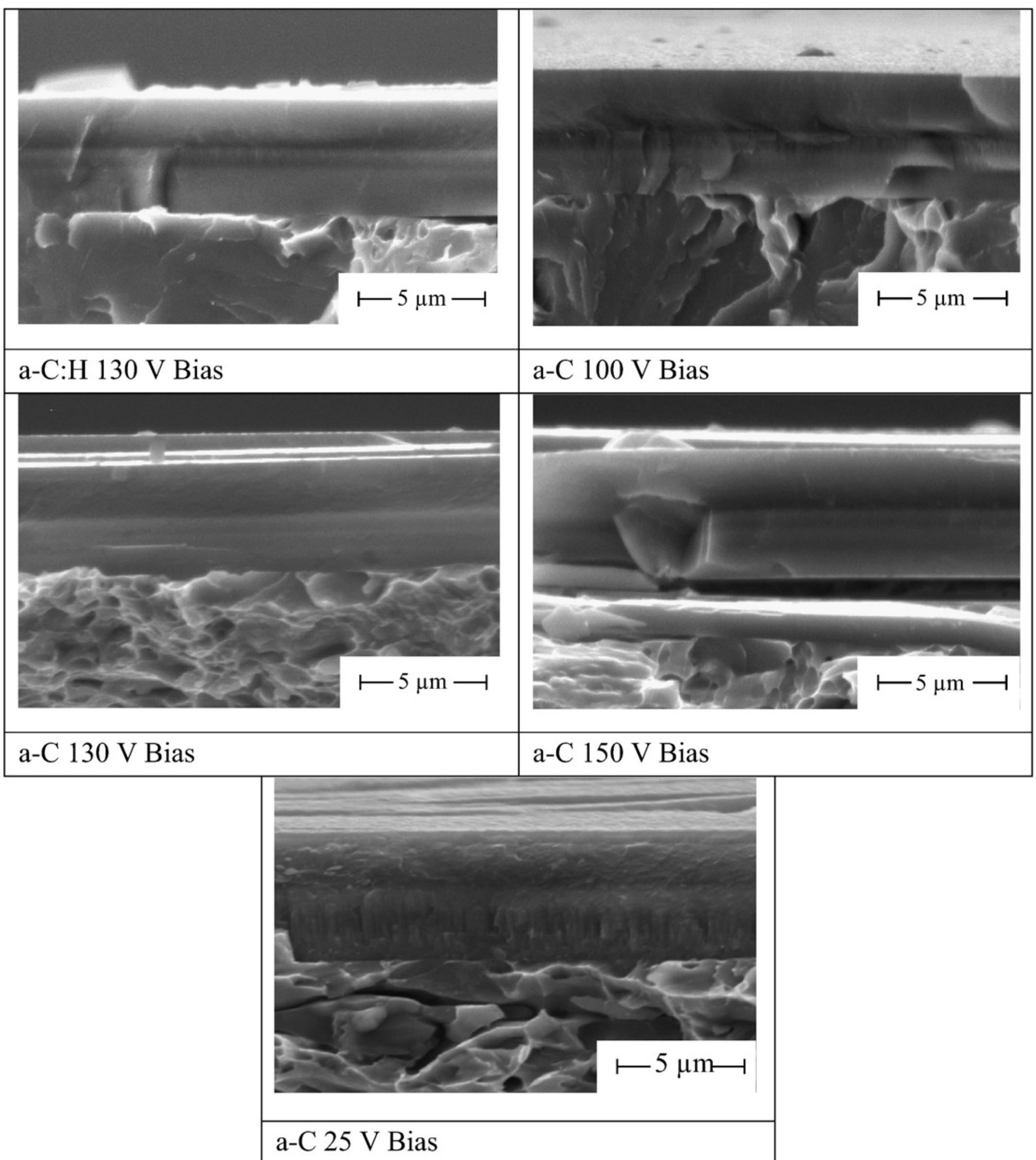

Fig. 1. Fracture surfaces of the examined DLC-multilayer systems.