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Characterization of fatigue and adhesion properties of a-C:H/CrN coatings on bearing rings by impact tests

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ABSTRACT

The impact test is used for the quantitative assessment of various properties of thin hard coatings, deposited on machine elements, tools etc. This test is mainly applied on coated specimens with simple geometries such as of cutting inserts and coated plates. In the described investigations, perpendicular and inclined impact tests were conducted directly on PVD coated bearing rings. The tests were performed with the aid of appropriate fixtures on the internal cylindrical surface of the outer bearing ring, as well as on the external one of the inner ring. Through a developed FEM simulation of the contact between the indenter ball and the cylindrical ring surfaces during the perpendicular and the inclined impact test, the film fatigue endurance stress was determined and the coating's adhesion was quantified. The mechanical properties of the applied thin films and substrates, used in the FEM calculations, were detected by nanoindentations and appropriate results evaluation. The obtained film fatigue endurance stress of the investigated coating can be considered as adequate however the coating adhesion is assessed as poor.

1. Introduction

The performance of bearings is restricted by the tribological behavior of their steel rings, which is affected by many factors such as vibration, load, speed, lubricant, debris etc. In some cases, specific thin hard coatings can and have been used to increase the performance of steel bearings [1–7]. Significant parameters that have to be investigated on the coated bearing rings are the coating fatigue and adhesion strength, as a premature film failure delimits the service life of the whole bearing.

The impact test is an effective method to characterize coatings cohesion, fatigue, adhesion micro abrasion etc. [8–13]. The possibility to test the coatings as deposited on the bearing ring surfaces, i.e. directly on the final product, is pivotal, because the PVD process significantly affects the attained film properties and adhesion. In the described investigations, nanoindentations were firstly conducted on coated bearing rings, to determine the film and the substrate mechanical strength properties with the aid of a finite elements method (FEM) supported results evaluation [14]. Furthermore, using developed jigs and fixtures, perpendicular and inclined impact tests were conducted directly on coated bearing rings. Finally, based on FEM simulations of the experimental procedures and appropriate calculations, the coating's fatigue and adhesion were quantitatively characterized.

2. Experimental procedures, devices and applied materials

The applied impact tester was developed and manufactured by the Laboratory of Machine Tools and Manufacturing Engineering of the Aristoteles University of Thessaloniki in conjunction with CEMECON AG. During the perpendicular impact test, a ceramic or cemented carbide ball applies repetitive impacts on the coating under a desired maximum load. In the case of the inclined impact test, the coated surface is placed at an inclination angle θ to the load direction. The impact tester is supported by the “ITEC+” software, which enables the determination of the coatings' fatigue properties in form of Smith and Woehler diagrams, based on the FEM simulation of the perpendicular impact test. The applied nanoindenter was a FISCHERSCOPE H100 [15]. The coating surface topomorphy and the impact imprint profiles were measured by a Taylor–Hobson SURTRONIC 3+ roughness measurement device. The coating thickness was determined by ball-cratering tests, using a device of CEMECON AG.

The developed fixture to hold the inner bearing ring is exhibited in Fig. 1a. The ring is mounted on an appropriate shaft and can be displaced in various positions along the shaft axis (X-axis). Moreover, this shaft can be moved vertically to its axis along the Y-direction at a specified distance L, thus enabling the conduct of inclined impact tests at an angle θ to the tested surface, as illustrated in Fig. 1b. The corresponding fixture for outer bearing rings is displayed in Fig. 1c.

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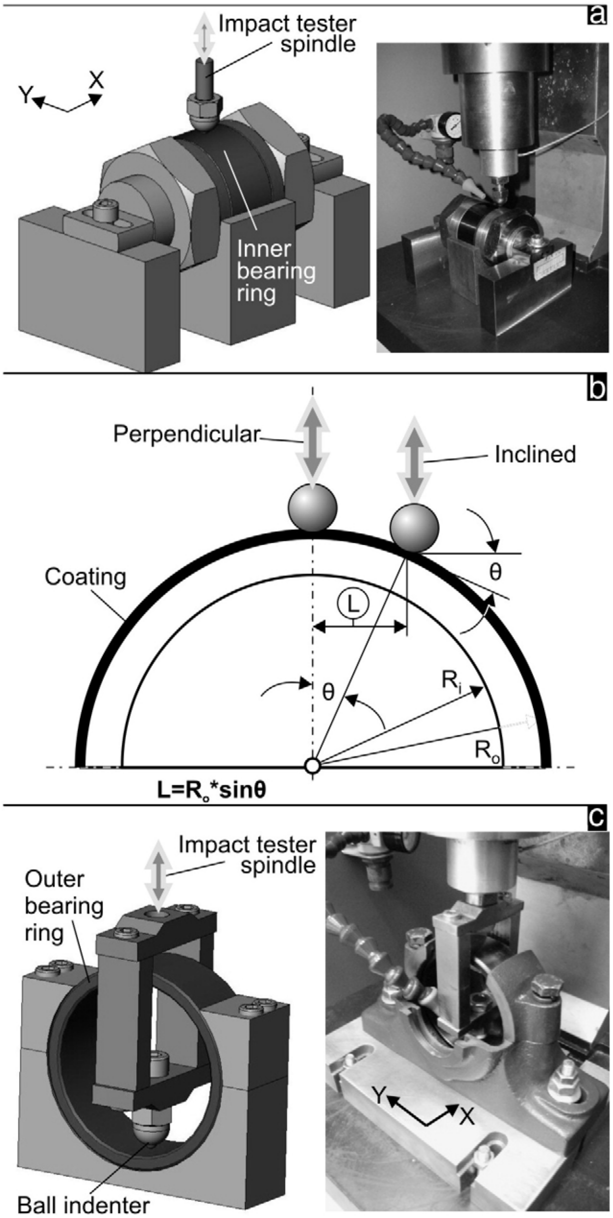

Fig. 1. a: Impact test arrangement for investigations on coated external cylindrical surfaces of bearing ring. b: Geometrical dependencies during the perpendicular and inclined impact test. c: Impact test setup to conduct experiments on a coated internal cylindrical surfaces of bearing ring.

The ring housing is fixed on an appropriate base, as shown in this figure. This can be displaced together with its base, along the *X*- or *Y*-axis, to enable perpendicular or inclined impact tests at various locations on the internal cylindrical ring surface.

The structure of the coating, deposited on the cylindrical regions of both bearing rings, is shown in Fig. 2. The superficial layer I consists mainly of a-C:H film with Cr gradation of approximately 2.2 µm thickness. The next layer II is mainly CrN with C gradation, with a thickness of ca. 1.6 µm. The coating deposition procedure was conducted at temperatures below 170 °C, to avoid annealing phenomena in the 100Cr6 steel substrate. In the FEM model, this structure was simulated assuming that two individual and perfectly adherent coatings were deposited, as presented in the bottom part of Fig. 2.

The determination of the coating stress–strain characteristics took place in two stages. Firstly, nanoindentations were conducted on the coated bearing rings at a maximum nanoindentation load of 5 mN, which led to a negligible deformation of layer II (see Fig. 3a). The stress–strain curve of layer I was determined by the FEM-supported evaluation method described in [14] and it is monitored in the corresponding diagram of Fig. 3a. In this diagram, the elasto-plastic characteristics of the 100Cr6 substrate are also demonstrated. These are determined according to the same procedure on uncoated regions of the same coated bearing rings. In a further investigation stage, nanoindentations at a load of 50 mN were conducted, inducing a significant elasto-plastic deformation in layer II. Taking into account the already obtained data of layer I, the mechanical strength properties of layer II were determined by a numerical "trial and error" method introduced in [16]. The corresponding stress–strain curve is illustrated in the left diagram of Fig. 3b. To check the validity of these data, the penetration of the indenter into the layered PVD film was determined by FEM-calculations, up to an indentation load of 50 mN. These results were compared and found to be in a good agreement with the corresponding ones, measured through nanoindentations (see diagram in the right part of Fig. 3b). The determined

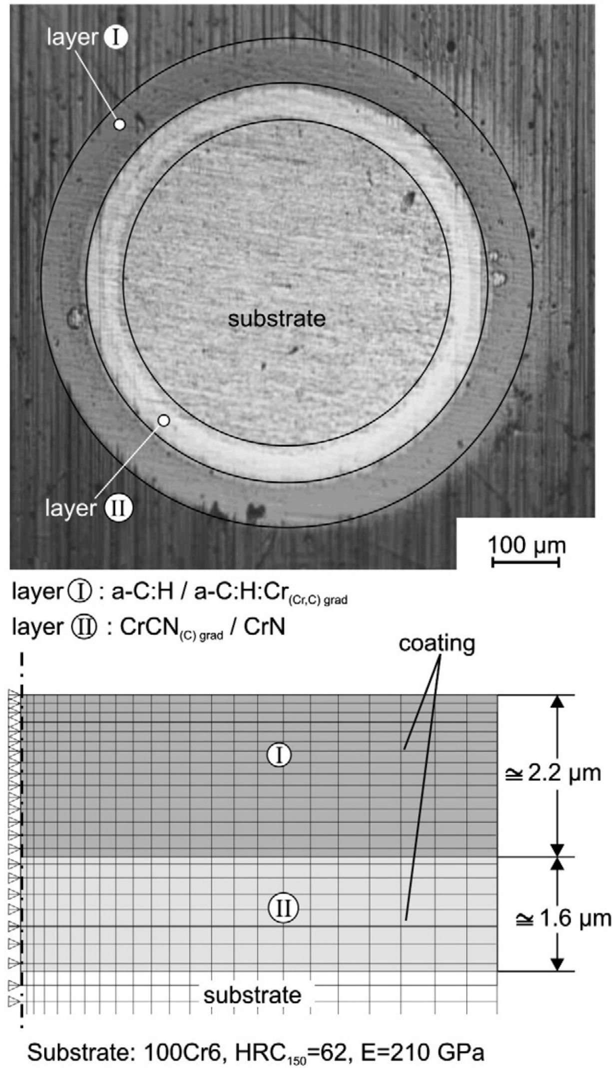

Fig. 2. Ball-cratering test imprint on the applied coating and the FEM simulation of its structure.