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Correlation between PVD coating strength properties and impact resistance at ambient and elevated temperatures

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ABSTRACT

The performance of PVD films depends on the operational mechanical and thermal loads of coated tools or components. To withstand these loads, sufficient film strength properties, at ambient and elevated temperatures are required. The present paper deals with the mechanical properties and the impact resistance of a TiAlN coating at temperatures up to 400 °C. Nanoindentations were conducted by a nanoindentation device, enabling measurements at room and elevated temperatures in an inert gas atmosphere. The obtained results were evaluated using appropriate FEM algorithms for determining the film's stress–strain curves, at the temperatures of the conducted nanoindentations. Moreover, perpendicular impact tests on the coated specimens were carried out up to 400 °C, for investigating the film's impact behaviour. The developed impressions were recorded by scanning electron microscopy and white light confocal measurements. The attained results demonstrate a non-linear dependence of the film fatigue properties versus the temperature, whereas a significant impact resistance improvement at approximately 150 °C develops. Finally, a convergence between the yield and the fatigue endurance stress versus the temperature was revealed.

1. Introduction

High mechanical and thermal loads act on coated tools especially at high cutting speeds. The detection of the temperature effect on the film mechanical properties is pivotal for optimizing the applied operational conditions and herewith for avoiding a premature film failure. Various techniques are employed to determine coating strength properties and friction coefficients at room and elevated temperatures, such as the tensile test [1,2] and tribological ones [3,4] respectively. Moreover, the impact test at elevated temperatures is a convenient experimental method for characterizing coating fatigue up to a temperature of approximately 500 °C [5–7]. This procedure is supported by FEM calculations, enabling the determination of the fatigue endurance stress versus the temperature [7]. On the other hand, nanoindentations at elevated temperatures by appropriate instruments conducted [8–11], contributed significantly in determining temperature dependent film strength properties. The latter technique is capable to conduct in "situ" measurements, thus rendering possible, a more accurate estimation of coating properties in a wide range of temperatures.

Recent nanoindentation results, revealed a micro-hardness decrease of a TiAlN coating, as the temperature grows [10]. In this research work, nanoindentations were carried out at temperatures of 25, 200 and 500 °C. Hereupon, it might be reasonable to check the film hardness, more systematically, at intermediate temperatures too. Therefore, in the frame of the present paper, nanoindentations and impact tests on a PVD TiAlN coating were conducted at numerous temperatures between 25 °C and 400 °C. Based on these results, film's stress strain curves [12] and fatigue endurance stresses [7] were calculated. Moreover, the convergence between the film yield and fatigue endurance stress was investigated. Finally the coating Vickers hardness was analytically estimated, at various temperatures, by methods documented in the literature [13,14]. Considering the previous data, the temperature dependent reduced film hardness H/E and the corresponding ratio H^3/E^2 [13] were defined. The latter ratio is associated with the film resistance to plastic deformation [15].

2. Experimental details

A $(Ti_{35}Al_{65})N$ coating, of approximately 3 μm thickness, was deposited on K05–K20 cemented carbides inserts by high ionization pulsing (HIP) and high ionization sputtering(HIS) PVD process [16]. By this method, a crystalline sub-micron film microstructure was obtained. The applied PVD films were produced using an industrial CC800/9 HPPMS coating unit of CemeCon AG [16]. Nanoindentations

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were applied on the examined film at temperatures of 25, 100, 150, 200, 300 and 400 °C by a high accuracy Micro Materials Ltd. instrument, as it is illustrated in Fig. 1 [8]. Up to a temperature of 500 °C, the crystalline structure of the investigated TiAlN film remains stable [16,17].

During the measurements, both indenter and specimen are heated. To avoid oxidations, the experiments are conducted in an inert gas (Ar) atmosphere. The contact between the sample and the indenter is schematically shown at the bottom figure part. In the conducted investigations, a Berkovich indenter was applied and the precise mathematical description of the equivalent tip geometry was facilitated, employing developed methods documented in the literature [18]. Taking into account the mean value of a sufficient number of nanoindentations, the SSCUBONI algorithm determines the film's elasto-plastic laws [12] at the temperatures of the conducted nanoindentations.

The fatigue properties of the examined coating at ambient and elevated temperatures were encountered through perpendicular impact tests, employing an appropriate device [5–7,19]. This device was developed and manufactured by the Laboratory for Machine Tools and Manufacturing Engineering of the Aristoteles University of Thessaloniki in conjunction with CemeCon AG. A new heating module was developed and implemented in the Impact Tester (IT) experimental setup. A high-efficiency heater and a hot air tool were integrated in the existing impact tester setup, capable of raising the test temperature over 400 °C (see Fig. 2). The power unit was upgraded to facilitate the integration of several new functions, safety sensors and controls. The operation of the heating module is

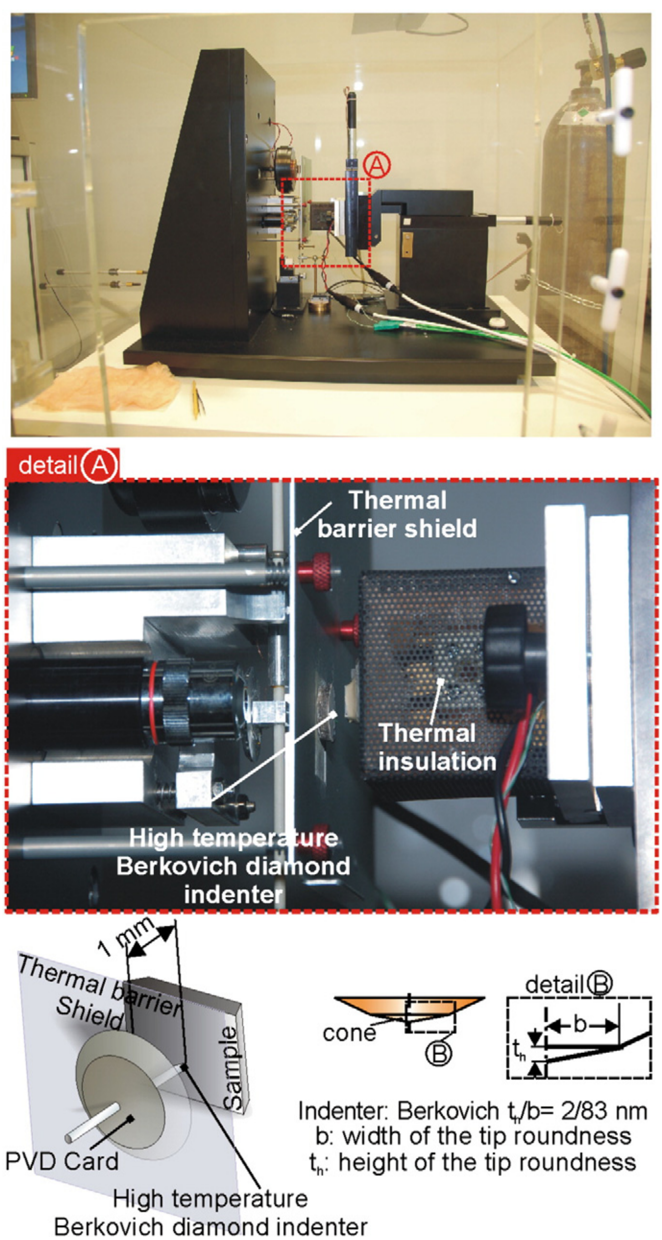

Fig. 1. Experimental set up for nanoindentations at ambient and elevated temperatures.

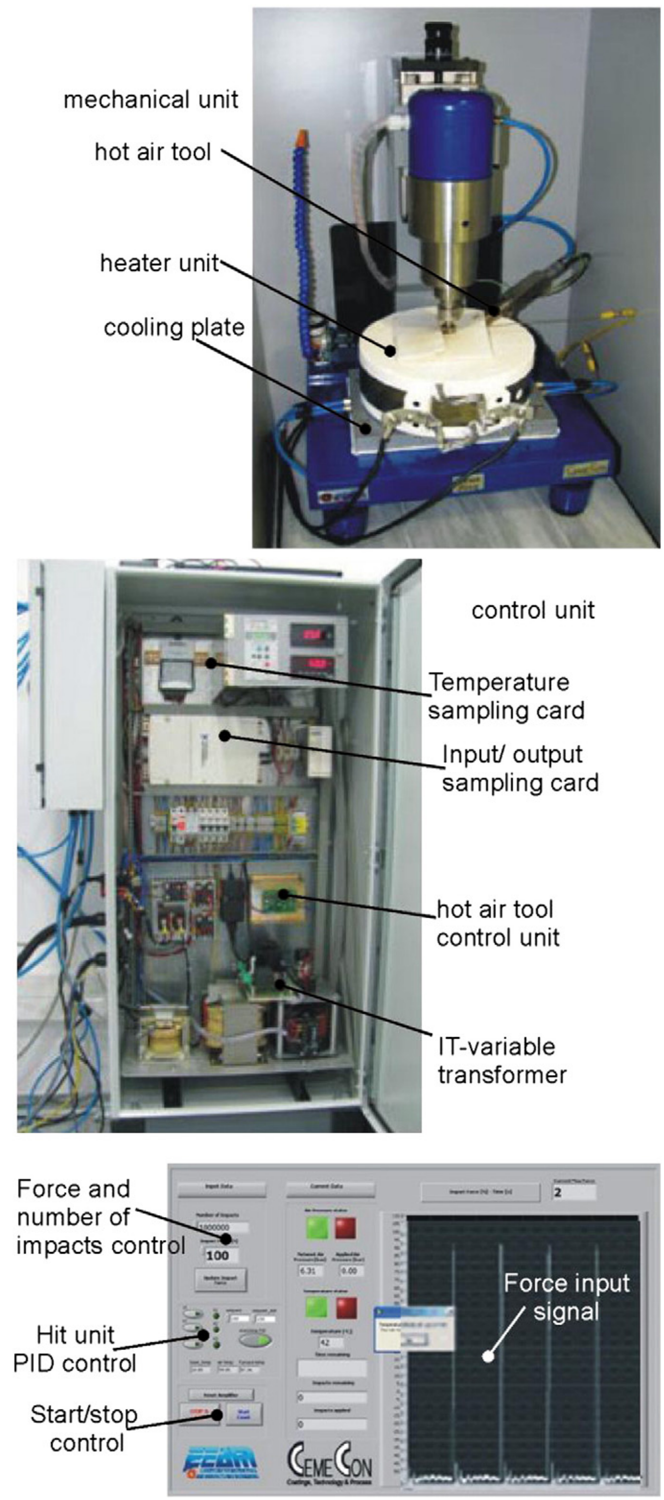

Fig. 2. The mechanical unit, the power supply equipment and the control panel of an impact tester for experiments at ambient and elevated temperatures.