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Experimental study of wear-induced delamination for DLC coated automotive components

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ABSTRACT

The trends in automotive industry are towards higher performance, improved reliability, reduced tolerances and more environmental friendly products. Wear resistance enhanced mechanical components exhibiting lower friction help achieving this major challenge. Diamond-Like Carbon (DLC) deposited on mechanical components operating under lubricated conditions at temperatures between 100 and 250 °C, efficiently decrease the friction coefficient and insure wear protection. Wear induced debonding and blistering of hard surface coatings is still a major problem in the automotive industry. There are several open questions. Where does debonding start? Where does the interface crack propagate? Where does it deviate leading to delamination? In this work, we show how the combination of the latest experimental techniques allows to answer these questions and thus better control wear. Blistering is influenced by the overall stress in the coating and the very local microstructure of the substrate. A combination of AFM and nano-indentation measurements, as well as FIB milling with in situ FEG-SEM observations and local chemical measurements by EDX, allows to observe closely and better understand wear-induced delamination. The new availability of such physical and chemical investigations should improve mechanical and physical-based models to predict wear and enhance coating adhesion.

1. Introduction

The trends in automotive industry are towards higher performance, improved reliability, reduced tolerances and more environmental friendly products. In addition, there is a strong demand for decreased fuel consumption. Wear resistant mechanical components exhibiting lower friction help achieving this major challenge. Diamond-Like Carbon (DLC) coatings, currently deposited, in mass production, on mechanical components operating under lubricated conditions at temperatures between 100 and 250 °C, efficiently decrease the friction coefficient (e.g. valve-train parts). Moreover, DLC coatings are used as wear protection (e.g. piston pins). Moving automotive components undergo several in service degradation mechanisms (smooth wear, tribochemical wear). Among all these mechanisms, coating delamination is occasionally detected. The coating seems to have peeled off in the form of stripes of a characteristic width, elongated along the sliding/motion direction revealing the base material (Fig. 1a).

Coating delamination and buckling lead to the propagation of interface cracks. Vast efforts have been dedicated to the theoretical analysis of interface crack propagation in model systems. Williams [1] determined the near crack stress field along a perfectly bonded interface between two linear elastic, homogeneous and isotropic materials. Sih et al. [2] found the stress singularities near an interface crack in a slab subjected to bending. These analyses predicted interpenetration of the crack faces [3–6]. By their pioneering work, assuming a contact zone at the crack tip, Comninou et al. [7–10] opened the field of interfacial fracture mechanics [11]. Aravas et al. [12] studied cracks between elastoplastic materials. Rice et al. [13], Evans et al. [14,15], Tvergaard et al. [16] and Hutchinson et al. [17,18] then applied interface fracture mechanics to film delamination. The theoretical framework of film delamination due to residual (process induced or thermal) stresses is well established [19–25]. The theoretical aspects of

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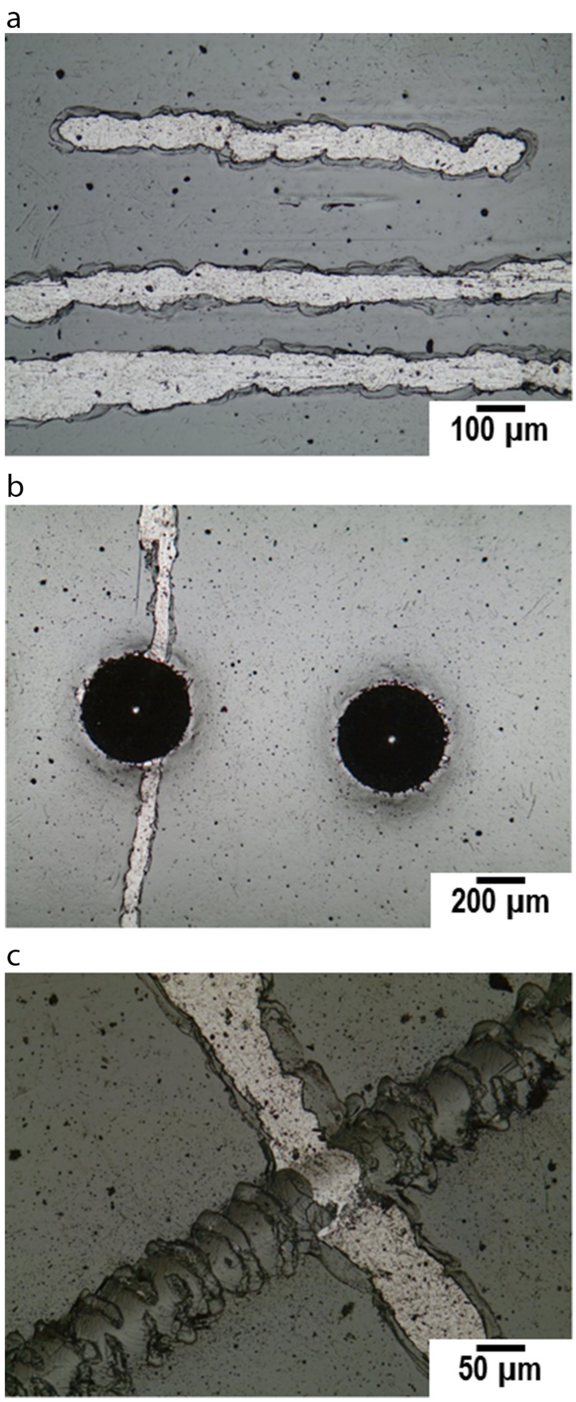

Fig. 1. (a) Wear induced delamination, (b,c) Classical adhesion tests DLC coated M2 steel. (a) Scratch test: wear trace for 2 different loads (30 and 40 N). b Rockwell indentation on damaged coating.

Table 1
Chemical composition of high speed M2 steel.

C	Mn	Si	Cr	W	Mo	V	Fe
0.85	0.28	0.30	4.15	6.15	5.00	1.85	Balance

delamination and crack propagation mechanisms in "model" configurations are now well understood.

Enormous efforts have also been spent on experimental coating characterization. For adhesion analyses the scratch and indentation

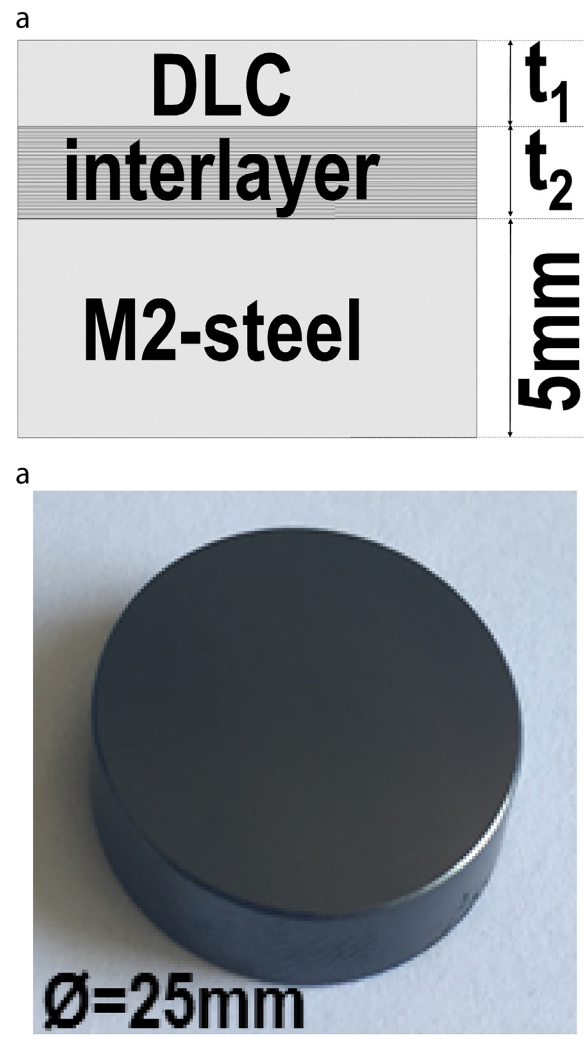

Fig. 2. Specimen for tribological test: (a) schematic representation, (b) optical view of a typical sample.

Table 2
Under-layer and DLC thicknesses, as measured by Calotest.

Underlayer t2 (μm)	0.6	0.8	1.0
DLC t_1 (μm)	0.2 1.2 2.5	0.2 1.2 2.5	0.2 1.2 2.5

tests are most popular. Numerous papers were dedicated to finite element simulations of these tests [26–28]. Steinmann et al. [29] presented a thorough experimental analysis of the intrinsic and extrinsic parameters influencing scratch test results on coated surfaces. Bull [30] presented a very interesting classification of thin film failure modes based on scratch test results. Drory and Hutchinson [31] discussed the best-suited tests for characterizing coating adhesion. However, *in service* damaged coatings exhibit all the listed failure modes. A huge literature survey published by Neuville et al. [32] review the various contributions of stress (interfacial, intrinsic and external) and conclude that high coating performance of DLC films is improved by combining a high density of covalent interface bonds, a low interface stress and a low total internal stress. Such a combination is not easy to achieve in the case of DLC films submitted to severe use conditions, and thus *in service* coating delamination is often observed. Adhesion tests like scratch testing or Rockwell indentation carried out, after in service coating debonding, on the remaining film, reveal no adhesive failure (Fig. 1b,