Material removal on lubricated steel gears with W-DLC-coated surfaces

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Abstract

The wear process that occurs on lubricated steel gears with thin, metal-containing diamond-like Carbon (Me-DLC) films deposited on the surface has been characterized using a variety of techniques that include the atomic force microscope and the focused ion beam imaging system. The profile of the tungsten-containing DLC (W-DLC) has been found to duplicate that of the original steel surface with peaks and valleys having amplitude up to 1 μm, superposed on a very thin (50 nm) Cr adhesion layer. Beneath the surface, imperfections are embedded in the steel. Wear occurs through the removal of the peaks by a polishing mechanism, leaving the valleys intact. When the peaks have been fully removed to create a plateau, the RMS roughness is approximately 35 nm. There are still pits corresponding to the original valleys up to 200 nm deep. When the remnant DLC becomes smaller than the amplitude of the peaks on the steel surface, the steel and the Cr adhesion layer become polished, causing the peaks to be eliminated, as well as the imperfections present in the subsurface. The resulting surface has RMS roughness with amplitude 25 nm, as well as small protuberances associated with the carbide particles in the steel.

Keywords: Diamond-like carbon; Wear; Focused ion beam; Atomic-force microscope

1. Introduction

The wear life of steel gears and bearings has been enhanced by deposition of a thin (approx. 1 μm thick) layer of diamond-like carbon (DLC), co-deposited with transition metals such as W and Cr (Me-DLC) [1–9]. The performance improvement has been related to the ability of the Me-DLC to form a smooth surface during initial wear-in. Such smoothing has a beneficial effect on the hydrodynamics of the lubrication layer. The enhanced durability requires that the removal rate of the DLC be small and that it remains intact, with no large-scale delamination [10–15]. The purpose of the present study is to characterize the mechanisms governing Me-DLC removal in actual gears, drawing upon insights gained from prior assessments [15–22].

Contact conditions comparable to those expected in gears have been explored using a rotating contact simulator [22]. These results demonstrated that the Cr adhesion layer between the DLC and the steel is sufficiently robust to inhibit interface de-adhesion. Accordingly, delaminations occur internal to the Me-DLC, extending parallel to the interface, consistent with its relatively low toughness (Γ ≈ 20 Jm⁻² [15]). Delamination and spalling have been observed in Cr-DLC [22], originating at ridge-imperfections on the steel surface. Conversely, W-DLC deposited on the same substrate resisted spalling and, instead, exhibited gradual smoothing of the original rough surface. The difference has been attributed to a combination of residual stress and toughness [22].

In the present study, the corresponding processes that occur in the actual W-DLC coated steel gear are characterized. For this purpose, tested gears are examined in the vicinity of the regions subject to the most extreme material removal rates. In particular, the sub-surface response has been characterized by using the focused ion beam (FIB) imaging system.

2. Material system and gear testing

Spur test gears, having 28 teeth and conforming to...