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Performance of CrN coatings under boundary lubrication

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ABSTRACT

In the case of metallic surfaces, the action of extreme-pressure (EP) and anti-wear (AW) additives is well understood and has been described in detail. However, this is not the case for coated surfaces. The aim of the present investigation was to determine the influence of additive type and concentration on the tribological behaviour of boundary-lubricated CrN coatings operating under different contact conditions. The results show that like for steel and diamond-like-carbon coatings, also in the case of CrN-coated contacts, the additive type, concentration and contact conditions have an influence on the tribological behaviour under boundary lubrication. The anti-wear additive has the smallest influence and results in complete protection of the CrN coating with respect to wear. On the other hand, the friction modifier gives the lowest friction, but high wear, while extreme-pressure additive concentrations above 1% are found to be too aggressive, even for the CrN/steel contact, and might lead to the formation of Cr–S tribofilms.

1. Introduction

The automotive industry is under great pressure to meet the legislative demands for producing environmentally friendly vehicles with reduced resource utilisation as well as to satisfy customer demands [1,2]. These challenges can be achieved by employing low-friction surfaces as well as by using high-strength, low-weight materials [3]. In terms of improving the performance of the engine components and forming very demanding, high-strength materials, the contact surfaces must show reduced friction, anti-adhesive properties and increased wear resistance [4]. Therefore, the automotive, tool and forming industries are keenly interested in various surface-engineering techniques, especially hard physical vapour deposition (PVD) and plasma-assisted chemical vapour deposition (PACVD) coatings. The motivation for the choice of hard coatings is mainly based on their superior mechanical properties, such as high hardness and excellent galling and wear resistance [5,6].

Nowadays, PVD and PACVD coatings are already in use for cutting tools, but increasingly so for machine elements and forming tools to improve their tribological properties. Some examples of the most common coatings are TiN, CrN and diamond-like carbon (DLC) [7–9]. Although TiN is still the most commonly used coating in cutting and forming applications, it exhibits a relatively high friction and high galling tendency [10]. DLC coatings, on the other hand, provide low friction and superior running-in properties [11]. Because of this, DLC coatings are extensively used for automotive engine components [12,13]. Another low-friction coating that is popular due to its high hardness, high thermal stability, galling resistance and excellent anti-corrosion properties is CrN [14]. As such, CrN coatings represent a viable alternative to TiN and are used for multiple tribological applications ranging from automotive components to forming tools and dies [15]. The highly textured surface and the large grain size of the CrN structure can also provide micro-reservoirs for lubricants [16], thus making CrN coatings suitable candidates also for components operating in lubricated conditions [17,18].

Tribological components, such as gears, bearings, piston rings, forming tools, etc., are usually lubricated. Most of these components operate under very severe contact conditions and hence adequate lubrication is essential for their optimal operation and the prevention of failure, even when using hard coatings [19]. However, in the case of coated components the compatibility between the hard coatings and the lubricants can pose a problem. The lubricants used in various tribological applications are formulated with different additives for optimal performance, which normally account for 4–10% in the fully formulated lubricant [20]. From the tribological point of view, the most important additives are the anti-wear (AW) additives used to reduce wear, the extreme-pressure (EP) additives used to prevent catastrophic failure under high-severity contact conditions, and the friction modifiers used for friction control [21]. These additives interact with the surface material to produce a protective tribochemical

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film, with its properties depending on the nature of the additive and the surface.

Most of the lubricant additives developed and adopted so far are formulated for ferrous materials, where the action of the additives is well understood and described in detail [21,22]. When introducing hard coatings, they are usually applied to existing components with minimal or even no changes to the system, including lubrication [22]. Therefore, the question of compatibility and the interactions of the lubricant additives and the hard coatings on the tribological performance become very important. The interaction could be synergistic, destructive or without any effect. During the past decade, tremendous efforts and research have been devoted to the lubrication of DLC coatings. The evidence for tribochemical reactions on DLC coatings and their improved frictional and wear performance using additive-containing lubricants are well reported and explained [13,19,22–26]. On the other hand, although suitable performance for CrN coatings under lubricated conditions has been reported [25], very little work has been done to understand the effect of the additive type and concentration. Work by Haque et al. [27] indicates that also in the case of CrN/cast-iron systems AW and friction-modifier (FM) additives give a positive effect in terms of low friction and anti-wear performance. In both cases the formation of tribofilms on the CrN coating was reported.

The aim of the present investigation was to determine the influence of the additive type and concentration on the tribological behaviour of CrN coatings when operating under boundary lubrication. Furthermore, the research was also focused on the effect of the contact conditions, including load, sliding speed and oil temperature.

2. Experimental

2.1 Materials and coatings

In the present study, a commercial ∼2-μm-thick monolayer CrN coating with a hardness of 1750 HV was used. The CrN coatings were deposited on hardened ball-bearing steel discs (AISI 52100, 850 HV). Hardened AISI 52100 steel was also used as the reference material in the case of the non-coated tribological contact. Prior to coating the steel discs were ground and polished to a surface roughness of $R_a = 0.05$ μm, cleaned in an ultrasonic bath in acetone for 15 min and dried in hot air. For the CrN coatings' deposition, an industrial closed-field unbalanced magnetron sputtering system with chromium targets was used and the substrate temperature was kept below 250 °C during the deposition. In order to ensure good coating-to-substrate adhesion a thin Cr interlayer of about 100 nm was used.

2.2 Lubricants

The base-stock lubricant used in this investigation was poly-alpha-olefin (PAO 8) oil without any additives and a kinematic viscosity ν_{40} of 46.6 mm^2/s. The tribological testing was performed with pure PAO8 oil and PAO8 mixed with commercial extreme-pressure (EP), anti-wear (AW) or friction-modifier (FM) additives. The additives were mixed with the base-stock PAO8 lubricant in concentrations from 0.1% to 10%. The EP additive was sulphur-based sulfurized olefin polysulfide ($\nu_{40} = 650$ cSt, $\rho_{15} = 0.98$ g/ml); the AW additive was a phosphorous-based mixture of diamine monohexyl phosphate and amine dihexyl phosphate ($\nu_{40} = 240$ cSt, $\rho_{15} = 0.94$ g/ml); while oleic acid ($\nu_{40} = 20$ cSt, $\rho_{15} = 0.89$ g/ml) was used as the FM additive.

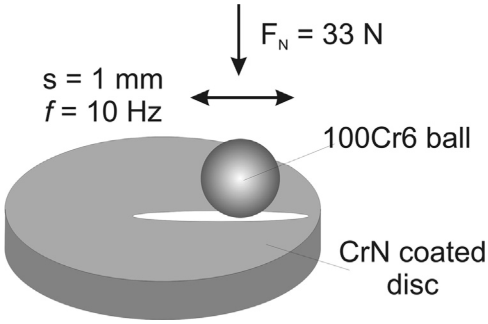

Fig. 1. Ball-on-disc test setup.

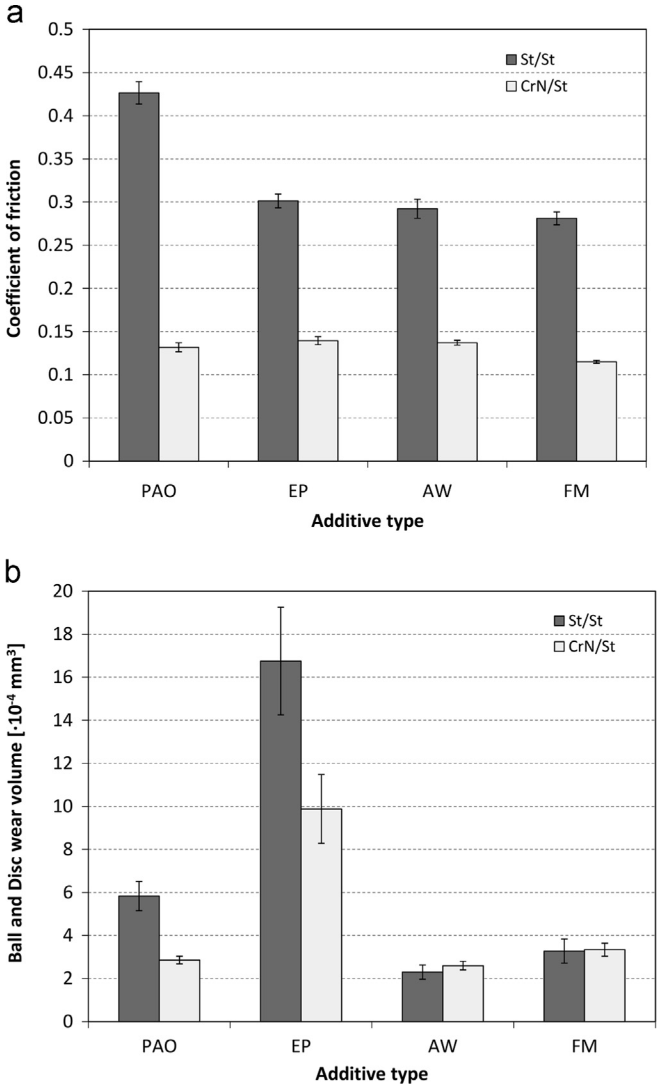

Fig. 2. (a) Steady-state coefficient of friction and (b) ball-and-disc wear volume for steel/steel and CrN/steel contact ($p_H = 1.5$ GPa, $\nu_s = 0.02$ m/s, $T = 50$ °C, 1% additive concentration).

2.3 Friction and wear testing

The oil-lubricated wear and friction tests were conducted on an Optimol SRV test rig under reciprocating sliding-contact conditions using a ball-on-flat configuration and a stroke length of 1 mm (Fig. 1). The oscillating counter-body was a standard 10-mm-diameter steel ball bearing with a hardness of 750 HV and