Tribological behavior of Ti-based thin film coatings under boundary lubrication regime.

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TRIBOLOGICAL BEHAVIOR OF Ti-BASED THIN FILM COATINGS UNDER BOUNDARY LUBRICATION REGIME

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INTRODUCTION

Thin film hard coatings are increasingly being used for tribological application [1-3] usually to address persistent failure or life limiting events in components. Vast majority of tribological components are lubricated either with oil or grease. Lubricants are normally formulated with functional additives to provide specific desired attributes such as reduced friction, low wear etc. The additives function through chemical interaction and reaction with the surface being lubricated, especially under boundary lubrication regime. Hence, lubricant formulation is surface specific. Since most, if not all, tribological components are made of ferrous materials, currently available lubricant additives are typically formulated for ferrous surfaces. The impact of thin-film coatings on tribological performance of lubricated interfaces, particularly under boundary lubrication regime is still unclear; in spite of recent increased research activities on this issue. Most of the studies this far concentrate on the diamond-like-carbon (DLC) coatings [4-6]. Among Ti-based coatings, TiN is perhaps the most matured coating in term of tribological application. In spite of some limited studies [7], the tribological performance of Ti-based coatings under boundary lubrication regime is poorly understood. This paper presents experimental investigation of friction and wear behavior of two Ti-based coatings when lubricated with four different oils.

EXPERIMENTAL DETAILS

Friction and wear tests were conducted with a roller-on-flat in reciprocating sliding line contact configuration, as illustrated in Figure1. The 6.3 mm diameter and 10.3 mm long uncoated steel roller was made of hardened 4140 steel (56 Rc) and has a surface roughness 0.2 µm Ra. The 2”x1.5”x0.25” flat specimens were made of case carburized 4118 steel with hardness of (64.5 Rc). The surface was polished to a finish of 0.019 µm Ra. TiN coating and TiB_2 coating were deposited on the flat surface by a PVD process. Some properties of the coatings are summarized on table I. Lubricated tests were conducted using normal load of 150N (0.33 GPa. Average Hertzian pressure), stroke length of 10 mm, frequency of 0.5 Hz, producing a linear velocity of 10mm/s, and temperature 100 ºC for a duration of 3 hrs. Tests were conducted with four different lubricants as shown in table II. Lubricant A and B are fully formulated for ferrous materials; A is optimized for friction reduction, while lubricant B is optimized for wear protection. Calculated λ ratios for all the lubricants at the start and finish of tests were in the average of 0.04-0.22; all of which are in boundary lubrication regime.

Table I: Properties of the coatings

Samples	Deposition method	Type	Thickness (µm)	Manufacture Hardness (GPa)	Roughness (nm)
TiN	PVD	Monolayer	3.7	29-30	87
TiB2	PVD	Monolayer	1.9	34-37	30
4118	none	No layer	0	7	19

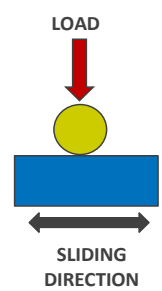


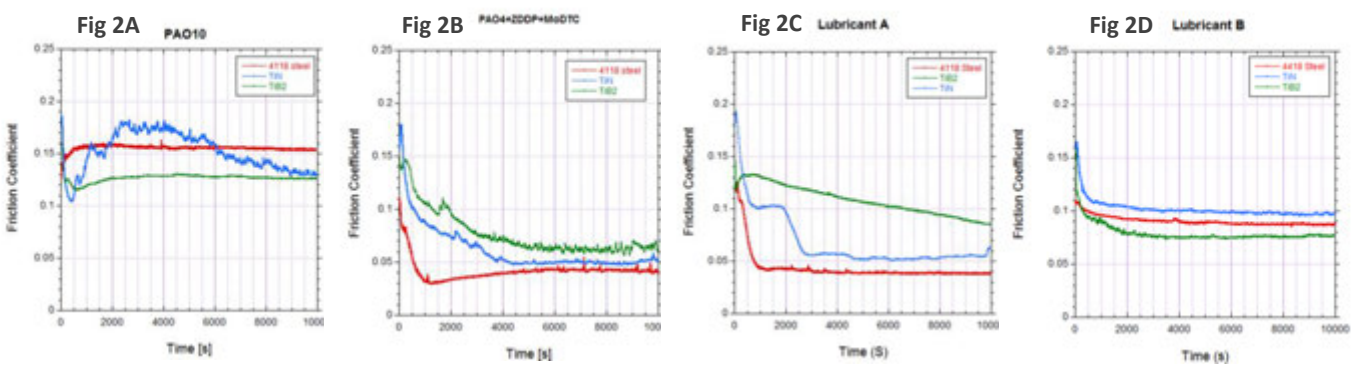
Figure 1: Test rig configuration

Table II: Properties of the lubricants

LUBRICANT	PAO-10	PAO-4+ Additives	Synthetic A	Synthetic B
Viscosity 40°C (cSt)	71.1	15-20	233.5	132
Viscosity 100°C (cSt)	10.70	4.20	18.7	17.5
Viscosity Index	-	-	92	146
Flash point (°C)	272	204	235	221
Pour point (°C)	-51	-57	-15, 5	-45
Density (kg/m^3) at 15.6C	837	819	905	860

RESULTS AND DISCUSSION

The friction behavior for the Ti-based coatings and the uncoated substrate when tested with the different lubricants is summarized in Figure 2. When tested in PAO10 without additives, friction coefficients for both coatings decreased rapidly in a very short time from an initial value (0.2-0.15). After the initial decrease, friction for TiB_2 remains nearly constant with a steady value (0.125), while friction coefficient for TiN increased to a peak value followed by gradual decrease to same value of TiB_2. Friction for the uncoated steel flat (0.155) was almost constant with time and higher than for both coatings at the conclusion of the test. When PAO was formulated by adding ZDDP and MDTC additives, the frictional behavior for the coatings and uncoated substrate was similar, as illustrated in Fig 2B. In all cases, friction coefficient decreased with time to a constant value as the lubricant additives reacted with the surface materials to form a tribofilm. Effectiveness of the additives was more in the uncoated steel flat, as indicated by a steady friction coefficient of 0.04, followed by TiN (0.05) and TiB_2 (0.06) coatings. Fully formulated lubricant A was very effective in reducing friction for the uncoated steel flat to a value (0.04) as shown in Fig 2C. The same lubricant exhibited unusual friction behavior in the presence of coatings. For TiN coating, friction was reduced in a 2 steps process, suggesting that two sequential mechanisms may be occurring: the first one may be linked to molecular absorption, while the second one likely relates to chemical reaction of the additives and surface materials. Friction coefficient was reduced to a steady value of 0.055. Friction was also reduced for TiB_2 coating, but at a much slower rate. Indeed no steady value was reached before the conclusion of the test. Fully formulated Lubricant B had minimal impact in the frictional response of the different materials. Although friction was slightly reduced for both coating, steady friction coefficient for all the materials was similar (0.1).



At the conclusion of each test, the wear tracks of both the steel roller counterface and the flat surfaces were characterized. Because most of the wear was produced in the softer counterface (roller), and wear on the flats was minimal (not measurable), an assessment of the wear was conducted by measuring the wear on roller tracks only. A summary of these measurements is shown in Figure 3. Both coatings produced considerably more wear on the roller than the uncoated steel flat. This is expected considering the higher hardness of the coatings compared to the uncoated steel flat. Additives in the lubricants were very effective in minimizing roller wear for steel on steel contact. Indeed, only unformulated PAO caused wear in the roller comparable in order of magnitude to the coatings. Lubricant additives had minimal effect in reducing roller wear for steel on coating contacts. Wear in unformulated PAO was comparable (or less) than wear in the formulated lubricants. Between the coatings, TiB_2 produced considerably less wear on the steel roller than TiN. This is counter-intuitive

considering that TiB_2 is harder than TiN material and as such more wear on the roller would be expected. This is probably an indication of a yet unknown phenomenon taking place at the interphase which may also account for the unexpected lowest friction coefficient in the absence of additives.

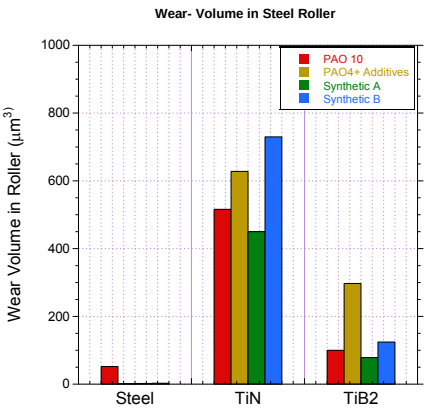


Figure 3: Roller wear volume after sliding against steel, TiB_2 and TiN coatings.

Characterization of the flats by optical and SEM microscopy showed minimal damage in all the materials tested. For the uncoated steel flat minimal damage was observed only for formulated lubricants; the additives in the lubricant interacted with the surface materials to form tribofilms in the contact area. The morphology, thickness and coverage of these films were different for different formulated lubricant, but all of them were effective in protecting the surface against damage and wear. In the absence of additives (basestock PAO), mild abrasive wear and oxidation were dominant on the surface. In the case Ti-based coatings, most of the tests resulted in minimal damage in the flats, due to the inability of the steel roller to wear the harder coating materials. No damage was observed on TiN coating flats regardless of the type of lubricant tested. Only formation of tribofilm and metal transfer from the roller was observed in reduced areas of the tracks. For TiB_2 coating the severity of damage was dependent on the type of lubricant. Abrasive wear was observed for tests with unformulated PAO10. For fully formulated Lubricant A, abrasive wear and cracking with partial delamination of the coating was observed. The other two lubricants produced minimal damage on TiB_2 surface. Formation of tribofilm and some metal transfer from the roller were the dominant mechanisms in the contact area. The extent of both, tribofilm formation and metal transfer on the coating surfaces are different for different lubricants, in all cases were limited to reduced bands of contact area where stresses were higher. In contrast, tribofilms formed on the uncoated steel flat had almost full coverage of the track.

CONCLUSION

Results of the present study showed that thin-film hard Ti-based coatings can interfere with the effectiveness of oil additives in term of friction and wear behavior. The coatings showed beneficial effect when tested with basestock synthetic PAO lubricant. Among the two coatings evaluated, TiB_2 showed better wear attributes on the counterface and lower friction in unformulated lubricant by a yet unknown phenomenon. More work is needed to effectively integrate coatings and lubricant additive technologies.

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KEYWORDS

Coatings, Boundary lubrication, Additive- deposited film.