Influence of base oil blends on micropitting

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1. Introduction

Micropitting is a type of surface fatigue that occurs in rolling-sliding contacts. It results from stress fluctuations caused by surface asperity interactions. Both the number and severity of asperity interactions increase at low lambda ratios, so it is becoming a significant challenge to develop low viscosity lubricants for gears and rolling bearings that mitigate micropitting effectively. It is of practical to understand the influence of dumbbell blending of polyalphaolefin (PAO) and polyisobuten (PIB) on micropitting. However, there has been very limited previous work on the tribological behaviour of dumbbell blends, and apparently none on micropitting. Therefore, this study aims to clarify the effect of dumbbell blends of PAOs and PIBs on micropitting [1].

2. Test methods

All micropitting tests were conducted using a Micropitting Rig (MPR). Test condition is shown in Table 1. MPR tests were carried out for 18 million cycles on the rollers. Table 2 (a) and (b) show the base oil ratios of 13 test blends; (a) six blends of pairs of PAOs and (b) seven PIB blends, six of PIB with PAO and one blend of two PIBs. All blends include a SP additive and were formulated to have a kinematic viscosity close to 7.0 mm^2/s at 100 ◦C and thus a dynamic viscosity of ca. 5.5 cP at 100 ◦C.

Table 1 MPR test condition

Maximum Hertzian pressure	2.0 GPa (550 N)
Entrainment speed	3.15 m/s
Slide-roll-ratio (SRR) $2*(U_{roller}-U_{disc})/(U_{roller}+U_{disc})$	-5% (roller surface speed U_{roller} is slower than disc surface speed, U_{disc})
Bulk oil temperature	100 °C (Contact inlet temperature: *ca.* 106 °C)
Test cycles	18 million (test time 20.4 hrs)

Table 2 Test oil formulations (a) PAO blends and (b) PIB blend.

(a) Oil code	Formulation (Base oil + SP additive)						DV, cP	KV, mm^2/s		VI
	PAO2	PAO4	PAO10	PAO40	PAO100	PAO300	100°C	40°C	100°C	
PAO4 +PAO10		31	69				5.5	38.8	6.9	136
PAO4 +PAO40		70		30			5.5	37.1	7.0	151
PAO2 +PAO40	45			55			5.5	35.1	7.1	171
PAO4 +PAO100		80			20		5.5	36.0	7.0	158
PAO4 +PAO300		86				14	5.5	34.2	6.9	169
PAO2 +PAO300	67					33	5.5	28.8	7.0	220

(b) Oil code	Formulation (Base oil + SP additive)							DV, cP	KV, mm^2/s		VI
	PAO2	PAO4	LV7	LV50	HV35	HV300	HV1900	100°C	40°C	100°C	
LV7 +LV50			16	84				5.6	58.4	7.0	65
PAO4 +LV50		19		81				5.5	54.3	7.0	82
PAO4 +HV35		72			28			5.6	40.9	7.0	132
PAO2 +HV35	49				51			5.6	41.8	7.1	145
PAO4 +HV300		82				18		5.5	38.8	6.9	137
PAO4 +HV1900		89					11	5.6	37.3	7.1	155
PAO2 +HV1900	77						23	5.5	31.5	7.0	196

3. Results

3.1 Effect of PAO and PIB blends on micropitting

Figure 1 shows representative optical micrographs of the rubbed track on the rollers at two different magnifications at the end of tests with these PAO blends, as well as the measured percentage of micropitted area on the roller wear track. PAO4 +PAO10 and PAO4 +PAO100 gave 59% pitted area ratio. Compared to this, while PAO4 +PAO40 reduced micropitting to 49%, PAO4 +PAO300 slightly increased the pitted area ratio to 67%. Figure 2 shows the evolution of friction coefficient in the tests. All lubricants gave a stable and equivalent friction coefficient during the tests of between 0.085 and 0.09.

Figure 3 shows representative optical micrographs of the wear tracks on the rollers at two different magnifications for the seven tested PIB dumbbell blends. PAO4 +HV300 gave a similar extent of micropitting to PAO4 +PAO10, providing 59% of pitted area ratio, while PAO4 +HV1900 slightly increased micropitting area to 65%. By contrast, LV7 +LV50 and PAO4 +LV50 very significantly reduced micropitting to 5% and 8% of pitted area ratio respectively. PAO4 +HV35 also provided a relatively low

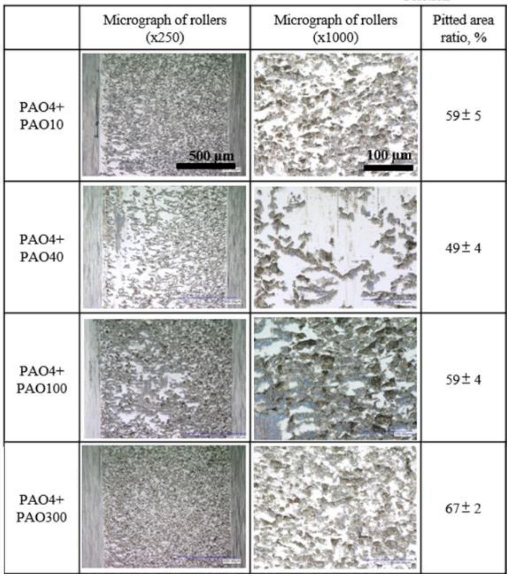


Fig. 1 Optical micrographs of wear tracks on rollers with the different PAO blends

level of micropitting, with 26% of pitted area ratio. Figure 4 shows the evolution of friction coefficient in the tests. While all lubricants reached a stable friction coefficient during the tests, unlike the PAO blends the various PIB blends showed different friction values. LV7 +LV50, PAO4 +LV50 and PAO4 +HV35 gave a relatively high friction coefficient, between 0.093 and 0.102 at the end of the tests. By contrast, the friction coefficients of PAO4 +HV300 and PAO4 +HV1900 were stable at 0.088 which is equivalent to that of PAO4 +PAO10.

The results presented here show that the PAO and PIB dumbbell blends significantly influence micropitting even when they have equivalent dynamic viscosity at the test temperature. Generally, lubricants can affect micropitting via the following three factors. Each of these was investigated.

i) Tribofilm formation
ii) Friction coefficient
iii) Oil film thickness

Based on several studies, it was found that EHD oil film thickness of lubricants significantly affected micropitting. Figure 5 plots alpha value at 100 ◦C of micropitted area for all fluids. It is evident that micropitted area reduces as alpha value and thus lambda ratio increases.

4. Conclusions

The main findings can be summarised as follows:

1. The type of dumbbell blends, especially with PIB blends, significantly influences micropitting despite their having equivalent dynamic viscosity at the test temperature.
2. Micropitting area increases as friction reduces in this study. This is quite contrary to micropitting studies that have investigated the effect of friction directly and this suggests that in the current work friction itself does not directly influence micropitting at the given EHL condition, probably because the dominant friction is EHD rather than boundary.
3. The micropitting area increase as EHD film thickness and thus lambda ratio reduces.
4. Since all blends have the equivalent dynamic viscosity at the test temperature, their variation in film thickness may originate from either or both of variation in effective pressure viscosity coefficient (alpha value) and inlet shear thinning.
5. High molecular base oils such as PAO300 and HV1900 showed significant temporary shear thinning at 10^7 s^{-1}, representative of EHD inlet shear rate condition.
6. When this inlet shear thinning is taken into account, there remains a significant variation of alpha value between the blends. This alpha value correlates with micropitting area via its impact on EHD film thickness.

5. Reference

[1] Ueda, Mao, Janet SS Wong, and Hugh Spikes. "Influence of dumbbell base oil blends on micropitting." *Tribology International* 185 (2023): 108578.

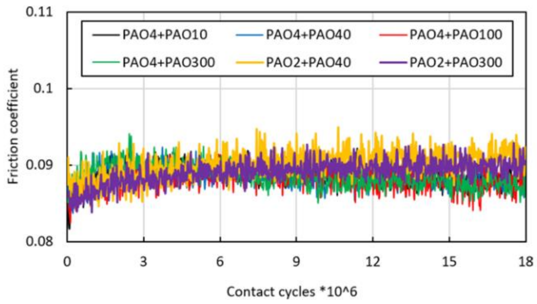


Fig. 2 Friction development in tests conducted with PAO dumbbell blends

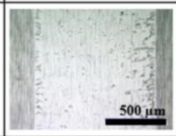
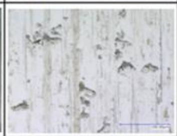
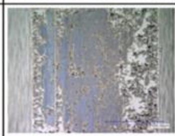
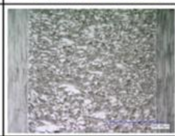
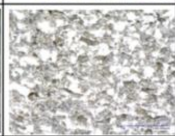
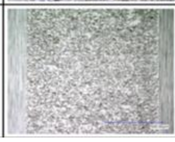
	Micrograph of rollers (x250)	Micrograph of rollers (x1000)	Pitted area ratio, %
LV7+ LV50			5±1
PAO4+ LV50			8±1
PAO4+ HV35			26±6
PAO4+ HV300			55±2
PAO4+ HV1900			65±3

Fig. 3 Optical micrographs of wear tracks on rollers with different PIB dumbbell blends

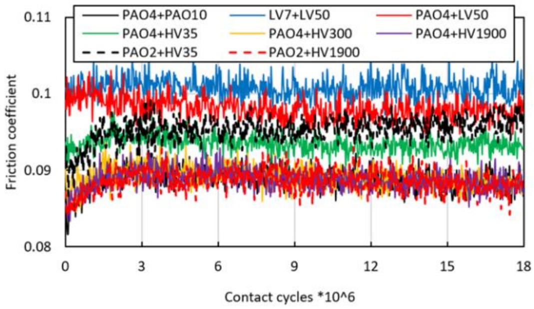


Fig. 4 Friction development in tests conducted with PIB dumbbell blends

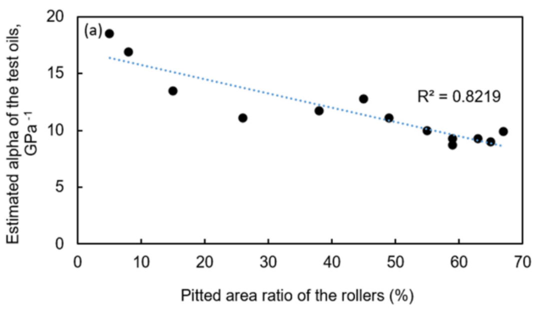


Fig. 5 The relationship between micropitted area ratio and estimated alpha at 100 ◦C