RT/DUROID 5813 REPLACEMENT INVESTIGATION

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ABSTRACT

RT/Duroid 5813 is a composite of PTFE, Molybdenum Disulphide (MoS_2) and chopped glass fibres and has been used extensively for many years as a simple, reliable, fully documented, self-lubricating bearing cage material in both terrestrial and space ball bearing applications. It has also been shown to be synergistic with thin films of MoS_2. However, its sole manufacturer, Rogers Corporation, has ceased production of Duroid and at present there is no alternative source of this material. There is now an urgent need to identify/validate a replacement material for space, and related, applications. This paper summarises the results from preliminary development tests performed by the European Space Tribology Laboratory (ESTL) to assess the fundamental friction and wear performance of five self-lubricating polymers identified as possible replacements.

1. INTRODUCTION

The materials initially selected for testing were SALOX M, LUBRIFLON 907, VESPEL SP-3, RULON E & PGM. A summary of the selection logic is as follows:

SALOX-M (40% Bronze/55% PTFE/5% MoS_2) was selected on the basis of pin-on-disc and bearing tests conducted at ESTL in previous research activities [Ref 1]. Salox M has also been put forward by several bearing manufacturers as a potential replacement to Duroid. LUBRIFLON 907 (40% Bronze/57% PTFE/ 3% MoS_2) is the European equivalent of Salox M (and 10% of the cost) and has also recently been tested by ESTL [Ref 2]. VESPEL SP-3 (Polyimide Resin with 15% (wt) MoS_2) was selected based on its low friction and wear characteristics in vacuum when coupled with 52100 bearing steel [Ref 3]. Vespel SP-3 has been tested extensively in cage-only lubricated bearings have been conducted in air, an environment known to be unsuitable for Vespel SP-3 if low friction/low bearing torque performance are required. The choice of RULON-E (PTFE/Glass Fibres/Molybdenum Powder) was based on test results reported in Japan in which Rulon-E cages were employed in steel bearings lubricated with sputtered MoS_2[Ref 4]. This work indicated that once the MoS_2 films had worn away, transferred material from the cage provided effective lubrication. PGM (PTFE/Glass Fibres/MoS_2) is a development material, manufactured by the Barden Corporation and its tribological properties have yet to be fully assessed.

The preliminary development activity, described in this paper, consisted of sliding pin-on-disc tribometer tests to ascertain fundamental friction and wear data. **DUROID** (75% PTFE/15% Glass Fibres/10% MoS_2) was also tested in order to provide a baseline comparison. All tests were conducted in line with the recommendation made in a Tribometer User's Guide compiled by ESTL [Ref 5]. Further details on the performance of Duroid as a cage material, and tribological issues involved in self lubricating cages of this type can be found in Refs 6 & 7.

2. TEST PARAMETERS

Table 1 lists the test parameters.

Table 1 - Test Parameters

Contact Type	Point contact (Pin-on-Disc).
Pin Materials	DUR, PGM, RUL & SP3 pins were dry machined to a rad. of curv. of 18mm and a nominal surface roughness of 0.4μmRa. SM & LUB pins were dry machined to a rad. of curv. of 30mm & Ra ~ 0.4μmRa.
Disc Material	SAE 52100 steel. Ra 0.05-0.15μm.
Lubrication	Unlubricated Disc.
Motion Type	Sliding - reciprocating/trapezium function.
Motion Speed	$0.1ms^{-1}$ & $0.01ms^{-1}$.
Stroke Length	6mm.
Load/Contact Stress	5.5N for a mean Hertz contact stress (MPa) ~ 2/3 the Yield Stress of the pin materials: DUR 14, PGM 9, RUL ~ 14, SP3 24, SM 10.5 & LUB ~ 7.
Environment	Atmospheres & Temperatures: Air - Rh 45% ± 5% & +20 ± 2°C. Vacuum < $5x10^{-6}$ torr & +20 ± 2°C. Air - Rh 45% ± 5% & +60 ±5 °C. Vacuum < $5x10^{-6}$ torr & +60 ± 5°C. Vacuum < $5x10^{-6}$ torr & -30 ± 5°C.
Failure/End	Sliding distance 1000m (166,600 strokes)
Tribological Data	1. Mean friction force measurement 2. Wear data & general observations. 3. Calculation of average specific wear rate (m^3/Nm) of pin materials.

Proceedings 7th European Space Mechanisms & Tribology Symposium, ESTEC, Noordwijk, The Netherlands, 1-3 October 1997, ESA SP-410 (October 1997)

NOTES: Tests were not conducted in air at -30°C to avoid condensation forming on the test specimen/rig. PGM/Air/+60°C/0.1ms^{-1} was omitted due to limited supply of this development material.

3. TEST RESULTS

The test results are summarised in **Figures 1 to 4** which show the mean steady-state friction coefficients and pin specific wear rates for each pin/disc combination tested.

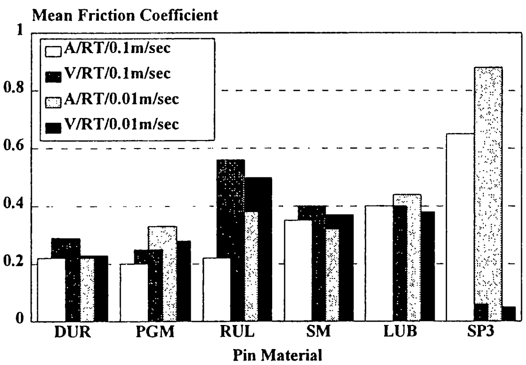

Figure 1 - Mean Friction Coefficients at RT

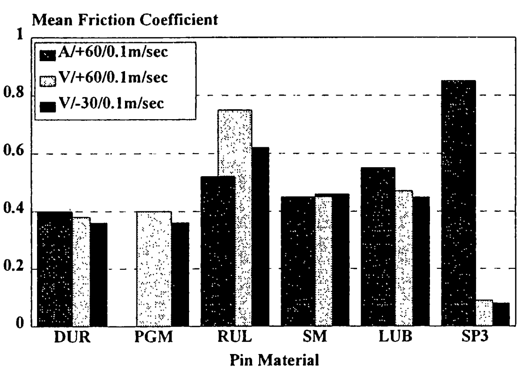

Figure 2 - Mean Friction Coefficients at +60/-30°C

Review of Mean Steady State Friction Data

At room temperature, the frictional performance of **DUROID** was found to be virtually independent of test environment and sliding speed, varying between 0.22-0.29. Friction increased to 0.38/0.4 at low/high temperatures. **PGM** performed in a similar way to Duroid with friction coefficients ranging between 0.22-0.28 at room temperature (in air the friction coefficient of PGM was noted to be increasing with test duration/sliding distance). At low/high temperatures the friction coefficient increased to 0.38/0.4. The frictional performance of **RULON-E** was found to be dependent on test environment and at room temperature was measured to be 0.22-0.38 in air increasing to 0.5-0.58 in vacuum. At higher temperatures the friction coefficient increased to 0.55 in air and 0.72 in vacuum. At low temperatures in vacuum the friction coefficient was measured to be 0.62. All tests performed with Rulon-E showed a steady increase in friction coefficient with test duration/sliding distance. **SALOX M & LUBRIFLON 907** performed in an almost identical manner, with friction values ranging between 0.36-0.43 at room temperature and increasing marginally to 0.42-0.55 at low/high temperatures. The friction performance of **VESPEL SP-3** was found to be highly susceptible to environment with friction coefficients dropping by over an order of magnitude between air and vacuum. In air friction coefficients of 0.64-0.88 were recorded. In vacuum the friction coefficient was initially high > 0.6, dropping rapidly to 0.06-0.09 once steady-state conditions were achieved.

Pin Specific Wear Rates & General Observations

Average specific wear rates were calculated from the dimensions of the pin wear scars after test completion (calculation of the specific wear rate assumes that wear is proportional to the load and is expressed in terms of volume removal per unit sliding distance per unit load (m^3/Nm). It should be noted that calculated specific wear rates should not be taken as absolute values, but considered in terms of variations within "orders of magnitude".

The most noticeable feature observed was the fact that the wear rates of all materials tested were generally higher in vacuum than in air, except for Vespel SP-3 which exhibited the opposite trend. In air, there were no obvious variations in wear rate as a function of changes in sliding speed over the range of speeds tested (0.01 to 0.1ms^{-1}). In vacuum the wear remained unchanged or decreased at the lower sliding speed of 0.01ms^{-1}. Wear rates generally increased with changes in temperature (+60°C & -30°C). The wear rates are discussed in more detail below. In the discussions all wear rates are in units of x 10^{-15} m^3/Nm.

At room temperature in air the wear rates of **DUROID** were low < 4, faint/translucent yellow/brown transfer films were generated on the steel discs. In vacuum the wear rates increased to 10-18 and the transfer films became thicker/darker brown. The highest wear rate of 18 was recorded in vacuum at -30°C, during this test large amounts of grey/black particles were produced in addition to the brown transfer film.

The wear rate of **PGM** did not exceed 10 throughout the whole test program, the lowest values of ~2 being recorded in air at room temperature. The transfer films generated were similar to those produced by Duroid. Faint yellow/brown transfer films were produced in air, thick/ darker brown transfer films formed in vacuum. Unlike Duroid, PGM did not produce a large amount of particulate debris at lower temperatures. The wear rate of PGM remained virtually unchanged with variations in temperature.

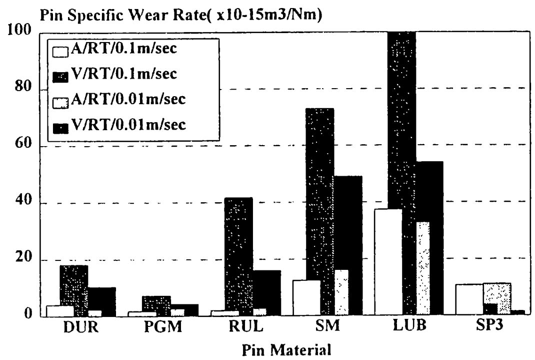

Figure 3 - Pin Specific Wear Rates at RT

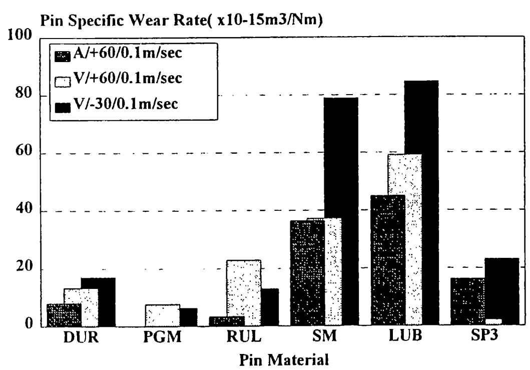

Figure 4 - Pin Specific Wear Rates at +60/-30°C

Although the friction and wear performance of PGM was comparable and in some cases superior to Duroid, one concerning feature was noted to have occurred on two of the steel discs after testing; the presence of scratches on the steel in the direction of pin motion. No scratches appeared with Duroid. All PGM pins/steel discs were inspected after test and there were no obvious signs of a third body, which could have accounted for the features observed. The possibility of glass fibres from the PGM pin scratching the disc was considered however there was no direct evidence to support this conclusion, although the fibres were more visible on the machined surfaces of the PGM pin than the Duroid. This anomaly should be investigated further if PGM is to be considered as a possible replacement to Duroid.

The wear rate of **Rulon E** varied with test environment. In air wear rates of <3 were recorded, and very faint yellow/brown transfer films generated on the steel discs. Wear rates increased to 15-20 in vacuum and inspection of the steel discs after testing revealed that the pin material had polished the surface of the steel, producing large amounts of black powder/debris. At higher temperatures thicker brown/black transfer films were visible in addition to a grey powdery coating and some loosely adhered grey/black particles. In air at room temperature the wear rate was < 15, this increased to ~ 40 with variations in temperature. In vacuum wear rates were calculated to be in excess of 50, the largest value of 80 being recorded in vacuum at -30°C. The transfer films generated differed between air and vacuum. In air, transfer films were thick yellow/brown, with some build up of compressed platelets of PTFE/bronze at the edges. In vacuum the transfer film was predominantly bronze, with a build up of a darker brown/bronze material at the edges.

LUBRIFLON behaved in a similar way to **SALOX M**, although the wear rates were all generally higher. In air at room temperature, wear rates of ~ 35 were measured, this increased to 60 at high temperatures, reaching a maximum of 80 at -30°C. Again the transfer films generated differed significantly between air and vacuum. In air, transfer films were yellow/brown, with a thick build up of compressed platelets of PTFE/bronze at the edges. In vacuum the transfer film was predominantly bronze, with a build up of a darker brown/bronze material at the edges.

At room temperature, the wear rates of **Vespel SP3** were all < 10, the lowest value of ~ 2 being recorded in vacuum at $0.01 ms^{-1}$. The high friction coefficients generated during the air tests and also during the initial "run-in" phase of the vacuum tests did not produce correspondingly high wear rates. At +60°C the wear rate increased to 15 in air, but remained low < 5 in vacuum. The highest wear rate of 22 was recorded in vacuum at -30°C. In air yellow/brown transfer films were produced, whereas in vacuum thin/translucent grey films were generated.

4. DISCUSSION

The performance of each material tested, relative to that of Duroid is reviewed briefly below.

PGM - The test results showed that under unlubricated conditions the friction and wear performance of PGM was almost identical to Duroid. Transfer films were thin/translucent. PGM produced less wear debris than Duroid at the lower temperatures of -30°C. However, the unexplained scratches on the steel discs were of concern. The possibility of glass fibres from the PGM pin scratching the disc were considered, however there was no direct evidence to support this conclusion. This anomaly should be investigated further if PGM is to be considered as a possible replacement to Duroid, in particular when used in conjunction with solid lubricant films of MoS_2, where abrasive particles/fibres could damage the lubricating films.

RULON-E **-** The frictional performance of Rulon-E was found to be dependent on test environment, the friction increased with test duration/sliding speed, reaching a level over three twice that measured for Duroid. Under unlubricated conditions the performance of Rulon E was not comparable to Duroid. Its performance may be enhanced when combined with MoS_2, however it may abrade the soft film. **NOTE**: Rulon E cannot be considered as a possible replacement to Duroid as ESTL have recently been informed by the manufacturers that the material is no longer commercially available.

SALOX-M & LUBRIFLON 907 **-** The friction and wear performance of Salox M and Lubriflon were virtually identical. At room temperature the friction coefficients were almost twice those recorded for Duroid, however, unlike Duroid, the friction coefficient of Salox M and Lubriflon remained relatively constant with changes in temperature in the range of +60°C to -30°C. The points of concern for Salox M & Lubriflon was the high wear rates and large amounts of debris and thick transfer films generated during testing, in particular in vacuum where the material to preferentially transfer was bronze. The MoS_2/PTFE seemed to be ineffective. Large amounts of transfer film will tend to "clog up" bearings and bronze transfer will produce high friction coefficients. These features have already been seen in bearings lubricated solely with Salox M cages. Salox M and Lubriflon are also heavier than Duroid and relatively poor to machine when compared to the other composite materials.

VESPEL SP-3 **-** The in-vacuo steady-state friction coefficients of Vespel SP-3 were four times lower than Duroid. However Vespel SP-3 must be allowed to "run-in" (each time it is introduced to vacuum) in order to overcome the initial high friction values. In air, Vespel SP-3 is not considered suitable on friction performance alone. In-vacuo wear rates were lower than those measured for Duroid, transfer films were thin/translucent, debris production in vacuum was also low. Even in air, the high friction coefficients did not generate excessively high wear rates/debris. Vespel SP-3 is light, easy to machine. However it is stiffer than other composites tested and as a cage material, may tend to cause cage hang-up.

5. CONCLUSIONS & RECOMMENDATIONS

Possibilities as Replacements to Duroid in Cage-Only Lubricated Bearings & Bearings Lubricated with Sputtered Films of MoS_2

PGM - **Good Candidate.** Performed in a similar way to Duroid, however concerns over possibilities of generating steel wear due to constituent materials. Glass fibres may damage MoS_2 film.

RULON E - **No longer commercially available.**

SALOX M & LUBRIFLON - **Outsider.** Heavy transfer film in vacuum. High density. Most difficult to machine and may produce "out-of round" cages if machined incorrectly. Should be considered in conjunction with additional lubricant source to reduce the bronze transfer in vacuum.

VESPEL SP-3 - **Unconventional Possibility.** Poor friction performance in air. Excellent in vacuum provided that the "run-in" period can be tolerated. Easy to machine, however the material stiffness may cause a problem and should be considered in the cage design.

Recommendations

PGM and Vespel SP-3 should be considered in future cage development tests in conjunction with solid lubricant films of sputtered MoS_2. Vespel SP-3 should also be considered as a cage material in cage-only lubricated bearings, and should operate satisfactorily if an effective transfer film is generated.

6. REFERENCES

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