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ASSESSMENT OF POLYMER COMPOSITES FOR HYDRODYNAMIC JOURNAL BEARING APPLICATIONS

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ABSTRACT

Polymer composites are employed as facing materials in hydrodynamic bearings for their low friction and “compliant” properties which play an important role during machinery operation. In journal bearings, this low friction property can be of significant importance during start and stop cycles when insufficient oil is available to fully separate the surfaces in relative motion. Current work is aimed at determining a suitable material for use in hydrodynamic journal bearings. This study investigates friction and wear encountered during the transition from the stationary state to operational speed (acceleration) during initial start-up. This is examined for virgin PTFE together with a series of commercially available PTFE-based composites and a babbitt material in boundary / mixed lubrication conditions. Tests are performed using a standard laboratory block-on-ring test apparatus with a VG32 mineral oil.

1 INTRODUCTION

The advantages associated with polymer composites in respect to bearing applications have been extensively studied and researched in recent times [1]. Polymers such as poly-tetra-fluoro-ethylene (PTFE) have raised considerable interest when selecting materials for such applications. In the main, this is due to their inherent characteristics such as low coefficient of friction, a desirable factor in both dry (unlubricated) and boundary / mixed lubricated contacts.

A considerable number of studies have been carried out to examine the friction and wear characteristics of PTFE and other polymer composites. A review of these can be found in [2,3] However, despite the amount of published work, relatively little has been done in investigating oil lubricated contacts.

The stop / start stage is of particular interest since hydrodynamic bearings are most susceptible to damage during periods of transient operating conditions. Polymer materials can offer a potential solution to improve bearing operation and performance without sacrificing integrity.

Babbitt (white metal) is a relatively soft material, an amalgam of metals such as tin, copper and antimony, traditionally used as a facing material in hydrodynamic thrust and journal bearings. It provides a layer of material that it is easily “smeared” and can take care of small particles that may find their way into the oil film / contact region, reducing the risk for damage to the bulk material of the bearing. These properties, while positive for the application, mean that it is prone to wear should contact occur between shaft and bearing.

Wear in a lead-bronze alloy hydrodynamic journal bearing as a result of repeated start / stop was studied in [4]. This showed wear occurring only during the start-up phase.

In our previous study [5], a PTFE / glass fibre composite was utilised as a facing material for the pads of a tilting-pad thrust bearing. Results from laboratory tests using this bearing showed improved operational performance when compared with that for an identical bearing with a babbitt facing material.

Further investigations regarding PTFE faced thrust bearings were performed in [6,7].

In [8], a series of tests were performed at a constant sliding speed of 10.2 m/s and varying load (49-1192 N) under lubricated conditions in a block-on-ring contact to compare friction and wear values for PTFE, PTFE composites and a babbitt material. The PTFE composites were seen to perform better than the pure PTFE and babbitt under severe lubricated sliding conditions.

Friction and wear coefficients of polymer composites are strongly affected by the type, quantity and orientation of filler materials, the most common forms being fibres and particles. In [9] it was found that inorganic (metal) filler has the ability to reduce PTFE wear. Decomposition of the filler was found to lead to bonding between the transfer film and counterface making the transfer film more difficult to remove. This bonding, combined with stability of the transfer film, was found to be important for wear reduction.

A number of experiments have been carried out to examine the relative merits of different polymer materials [10,11,12]. These have led to the development of a PEEK (polyether-ether-ketone) and carbon fibre composite specifically for use as a facing material for hydrodynamic thrust bearings.

Advantages with using a polymer facing material are seen to include the possibility for elimination of the requirement for “oil-jacking” during the machinery start-up phase. This is of particular relevance to large machines such as hydroelectric turbines which are regularly subjected to rapid “on demand” start-ups. This need for a means of eliminating contact between shaft and bearing also applies to large gas and steam turbines. During the procedure to stop such machinery, a period of slow running is necessary to allow the shaft to cool sufficiently in order to reduce the thermal deformation incurred during operation.

Little has been written concerning oil lubricated contacts in the start / stop transient case [4], specifically for hydrodynamic bearing applications such as those found in hydroelectric power plant. The aim of the present study is to assess the suitability of a series of polymer composite materials for employment as a facing material in a (fluid film) journal bearing. Given that initial conditions at start-up can be such that there is a dry, loaded, linear contact between the shaft and bearing, wear of the material and coefficient of friction are important factors in the first stages of machinery motion. Both values should be kept low to provide the equipment with as long a working lifetime as possible while meeting all operational requirements.

Experiments have been carried out in order to assess the performance of the composite materials in comparison with babbitt in dry start-up and boundary / mixed lubrication conditions for specific material pairings.

2 MATERIALS AND EQUIPMENT

All tests referred to in this paper are performed using commercially available polymer composite materials, loaded in a contact against common carbon steel. The materials have been chosen due to their ready availability and they form a good baseline for future development work. Details of the polymer composites are given in Table 1 below. The steel ring has an initial surface roughness, R_a , value of $\sim 0.8 \mu\text{m}$. The lubricant used in all tests is an ISO VG32 grade mineral turbine oil. Both ring and block are cleaned in an ultrasonic bath prior to testing.

Table 1 – Test materials

Material	Denotation
Virgin PTFE	PTFE
PTFE + 40% bronze	PB
PTFE + 25% carbon	PC
PTFE + 25% black glass	PBG
PTFE + 20% glass fibre + 5% Mo	PMo
PEEK + PTFE + carbon	PEEK
Babbitt (white metal)	Babbitt

Experiments are performed using a standard block-on-ring apparatus, as illustrated in Fig 1. This method is used as it is seen to be representative of the contact configuration found in a journal bearing. A sample of the polymer composite (1), 12.5 mm long x 7.5 mm wide, is loaded against the outer circumferential surface of a rotating steel ring (2).

The steel ring has an outer diameter of 40 mm and width 9.2 mm. Lubrication is supplied by means of a “drip feed” (3) in order to continuously supply clean oil to the contact. It should be noted that in this configuration, the contact is initially dry as the lubricant does not enter the contact until part of the first revolution has been completed.

The set-up used here is similar to that used in [8] although the load is applied vertically rather than horizontally.

Figure 1 – Schematic diagram of block-on-ring test apparatus showing oil drip feed.

3 EXPERIMENTAL PROCEDURE

For the tests carried out in this study, a load of 12 kg (118 N) is applied to the stationary ring. The ring is then accelerated to a final rotational speed of 1500 rpm (equivalent sliding speed 3.13 ms^{-1}). Each test sequence is run for a further period of 15 - 20 seconds once full speed has been reached. These settings have been chosen after performing tests to establish the maximum load / speed combination possible for the equipment with the specific materials being tested.

The first series of tests investigates peak “break-away” friction values for four materials (PTFE, PB, PC and Babbitt) at ten different acceleration rates. The same block and ring pairing for each material is used with all ten acceleration rates. Each test series begins with the slowest rate and continues with steadily increasing values. Acceleration is defined by the time required to reach 1500 rpm, namely: 25, 20, 18, 16, 14, 12, 10, 8, 6 and 4 seconds. These correspond to accelerations rates of $0.125 - 0.783 \text{ ms}^{-2}$.

Following each test run, the ring is stopped and oil and debris cleaned from both contact surfaces using a paper cloth and white spirits. More thorough cleaning of the surfaces is not deemed possible as this would require dismantling of the components and hence lead to possible mismatching of the contact surfaces upon reassembly. The test process is then repeated with the next acceleration rate.

A further set of experiments, using all 7 materials, has been performed to examine more closely the “break-away” friction at start-up for an acceleration rate of 0.52 ms^{-2} , representative of typical start-up acceleration in hydroelectric turbines. Immediately prior to start-up, the block is loaded against the ring which is then accelerated to 1500 rpm. This first run gives a “dry” start-up friction value. The load is then removed and the ring stopped. Once the ring is stationary, the load is reapplied and the process

repeated. This gives a “wet” start value for the friction coefficient. A final test is conducted at half load (6 kg, 59 N).

Relative material loss due to wear is examined both visually and by measuring the weight of the blocks prior to and after testing. Relative wear volumes and hence specific wear rates are then calculated using material density values.

4 RESULTS AND DISCUSSION

In all tests cases, an initial peak is seen for the coefficient of friction. This is particularly apparent for the first test run with each material, principally due to the initial dry nature of the contact. In certain cases the initial peak value can be almost twice that seen only a further couple of seconds into the test (see Figs 2 a and b).

Figure 2 – Coefficient of friction for initial “dry” test-runs for a) PTFE and b) babbitt

A sharp friction peak at the test start can clearly be seen in both illustrated cases. Values consequently drop as the surface wears in and lubricant is drawn into the contact.

In investigations performed with the babbitt material, friction results for the initial test runs show coefficient of friction values in the range 0.223 - 0.356, considerably higher than those found for the polymers.

A summary of “dry” start test results is given in Table 2 (average values). The data is illustrated in graphical form in Fig. 3. In this operational case, acceleration rate appears to exert an influence on the coefficient of friction – in general, values increase with acceleration rate.

Table 2 – Average peak coefficient of friction at dry start-up for two acceleration rates.

	PTFE	PB	PC	PBG	PMo	PEEK	Babbitt
0.125 ms⁻²	0.136	0.147	0.145	-	-	-	0.235
0.52 ms⁻²	0.157	0.142	0.157	0.211	0.182	0.143	0.325

Figure 3 - Peak coefficient of friction values at dry start-up (data from Table 2)

Table 3 – Peak coefficient of friction values at start-up at each acceleration rate.

	Acceleration time (seconds)								
	20	18	16	14	12	10	8	6	4
PTFE	0.101	0.083	0.078	0.064	0.109	0.078	0.077	0.080	0.106
PB	0.095	0.115	0.085	0.099	0.086	0.094	0.093	0.088	0.086
PC	0.097	0.095	0.096	0.097	0.101	0.094	0.092	0.098	0.093
Babbitt	0.128	0.124	0.113	0.124	0.124	0.161	0.105	0.154	0.124

Table 3 shows results obtained from the first series of experiments, recording the peak coefficient of friction values for a range of acceleration rates. These values are also

illustrated in Fig. 4. Results for the first (“dry”) test are not included. As stated previously, the contact was cleaned between each test i.e. excess lubricant was removed along with any wear debris remaining on the surfaces.

Values given in Table 3 show no clear effect from changing acceleration rate other than a drop from the initial high value measured during the first (“dry”) run in each series. This may be due to some lubricant remaining on the material surfaces or through material transfer from the softer test material onto the steel ring.

Figure 4 – Summary of peak coefficient of friction values as given in Table 3.

The theory concerning transfer of material from the block to the steel ring is backed up by measurements showing that the steel rings gain mass during the tests. Comparing the relative mass loss / gain for the block and ring respectively reveals that the loss of mass from the block is greater than or equal to the gain for the corresponding ring. This is true for all test cases. This will obviously have an impact on friction values following the initial “running-in” whereby the contact may change to a polymer–polymer junction. Visual observations during the initial test run with the babbitt material clearly show wear and transfer to the surface of the steel ring.

Tables 4 and 5 give friction data for the “wet” start tests. Values in Table 4 are for a test immediately following the first (“dry”) run while those in Table 5 show data for a second, subsequent “wet” start, this time at half the load (6kg). Unlike in the first set of acceleration tests (Table 3), the contact surfaces were not wiped clean between each run. Therefore lubricant remains within the contact region (although it is squeezed out when the load is re-applied) as well as, possibly, some wear debris.

From the measurements listed in Tables 4 and 5, the fact that different loads have been used does not appear to have any influence on friction values under wet start conditions. Differences between values for the different materials are also seen to be relatively small with similar values for all the materials.

Table 4 – Average peak coefficient of friction at “wet” start, 12kg loading.

PTFE	PB	PC	PBG	PMo	PEEK	Babbitt
0.099	0.095	0.111	0.107	0.096	0.109	0.116

Table 5 – Average peak coefficient of friction at “wet” start, 6kg loading.

PTFE	PB	PC	PBG	PMo	PEEK	Babbitt
0.105	0.092	0.096	0.119	0.104	0.112	0.121

Figure 5 – Comparison of “wet” start friction values (data from Tables 4 and 5)

The lower friction values for babbitt seen in Fig. 5 (in comparison to those found for dry start) can be explained by referring to the photograph of the worn material in Fig. 6.

Figure 6 – Worn surface of the Babbitt material showing wear “grooves”

As can be seen in the picture, the surface is crossed by a series of grooves, the result of the surface roughness of the ring. This groove pattern is not seen on the polymer

materials to this extent. It is thought that these grooves retain more oil in the contact at wet start thereby reducing friction by a greater amount than may otherwise be the case.

The plot in Fig. 7 gives the specific wear rates for the materials calculated from weight loss measurements. The composite materials are clearly seen to outperform both pure PTFE and the Babbitt material.

Figure 7 – Comparison of specific wear rates for the test materials (calculated from weight loss measurements)

Fillers can often play a double role: on one hand helping to bind the matrix material, combating creep and increasing tensile and compressive strength while on the other contributing properties of their own such as a means of building up a more effective transfer layer during sliding or a more conductive contact layer. By using scanning electron microscopy to examine the microscale, the filler materials are investigated more closely.

Carbon (graphite) is a solid lubricant and has been shown to reduce PTFE wear in both dry and lubricated contacts for thrust bearing applications [13]. In Fig. 8a, the PTFE / carbon composite does not appear to show much change in structure following wear.

For PB (Fig. 8b) it appears that the bronze material is not actually removed from the composite (unlike the PTFE matrix) but rather smeared across the contact forming a copper rich layer (confirmed by elemental analysis in the SEM). Given that the bronze has a much higher density than the PTFE, wear measurements using weight difference are sensitive to the relative component material loss.

Such a “smearing” effect is also seen for the PEEK based composite in Fig. 8c, apparently forming a PTFE enriched layer seen by the areas of lighter shading. The formation of a friction reducing PTFE film on the surface was seen for a similar material in dry running [14]. Wear scar width measurements suggest that the PEEK composite wears the least (it exhibits the narrowest wear scar).

a) unworn PC

a) worn PC

b) unworn PB

b) worn PB

c) unworn PEEK

c) worn PEEK

d) unworn PBG

d) worn PBG

Figure 8 – SEM micrographs of the material structure in the unworn and worn regions. Arrows show ring rolling direction.

Of all the composite materials, PBG is seen to give the highest friction at dry start. From the SEM images for this material in Fig. 8d), it can be seen that the glass fibres at the surface have been sheared through, in both the axial and the cross-sectional planes. In [15] it was found that the behaviour of fibres at the worn surface of a glass fibre reinforced PTFE composite have a strong influence on friction and wear properties. For the test loads of between 300 and 800 N, friction increased with load as a result of the ploughing action of the glass fibres into the steel counterface. It is clear that exposed glass fibres have a potential to cause damage to the shaft should a similar wear process occur in a bearing application.

The elastic modulus of the materials is to a large extent dependent on the filler material. In a journal bearing application it is desirable to have a certain degree of material compliability (surface deflection under the action of pressure) in order to counteract pressure peaks in the oil film. The thickness of this material layer will therefore be dependent on the elastic modulus of the composite in question. A less stiff material will permit the employment of a thinner layer.

From the results obtained during the current investigation it is clear that the polymer composites exhibit positive properties that demonstrate an improvement on the babbitt material in terms of break-away friction and wear. Further investigations can now be performed with these composites to determine the most suitable material composition for the intended bearing application.

5 CONCLUSIONS

The results obtained show that using a polymer composite material introduces clear benefits in comparison with pure PTFE and babbitt in terms of reduced wear and break-away friction at start-up.

At dry start, the break-away friction is seen to be influenced by the acceleration rate but in wet start conditions no difference is evident. Babbitt is shown to perform poorly in comparison with the polymer based materials with a coefficient of friction almost twice that of the composites.

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