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Advanced polymeric coatings for tilting pad bearings with application in the oil and gas industry

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ABSTRACT

Under extreme operating working conditions, the oil film in hydrodynamic bearings may get destroyed, resulting in mixed and boundary lubrication conditions; subsequently, the bearing surfaces might seize and cause catastrophic failure, rendering the machine non-operable. To address these extreme working conditions, three advanced coatings are proposed in this paper: polytetrafluoroethylene (PTFE) based, polyetheretherketone (PEEK) based and aromatic thermosetting polyester (ATSP) based coatings. A specialized high pressure tribometer, with a pin-on-disc configuration, combined with boundary/starved lubrication, was utilized to simulate the tilting pad bearing's severe working conditions encountered inside an Electrical Submersible Pump used in the oil and gas industry. Two sets of experiments, scuffing (step load) and constant load wear experiments were carried out. The coatings exhibited excellent performance compared to bare substrate materials. Scuffing experiments showed that all three coatings exhibited improved scuffing performance and wear experiments showed that the coatings exhibit relatively low coefficient of friction and low wear rate. Among coatings investigated, ATSP coating exhibited the best wear resistance.

1. Introduction

Hydrodynamic bearings are commonly used due to their high speed, high load capabilities and low friction [1]. Full film lubrication is expected for a hydrodynamic bearing, however severe working conditions could be encountered, such as during start and stop, lack of lubricant, elevated temperature and high load conditions. These severe conditions are likely to penetrate the oil film, resulting in mixed and boundary lubrication conditions [2,3]. White metal is dimensionally stable and easy to repair, and is widely used in hydrodynamic bearings (e.g., Babbitt). On the other hand white metal has a low melting point, which restricts its maximum life (combination of speed and load) [4]. Under severe working conditions, direct contact between the white metal and the rotating shaft or runner could yield frictional heat, leading to severe adhesive wear and burn damage of the white metal surface, with the possibility of catastrophic failure [3].

In many industries there is a need for more compact machines working under higher power densities, and thus resulting in severe working hydrodynamic bearing conditions [5]. Recent advances in subsea and deep-sea exploration require the development of next generation of interface materials, working under aggressive operating conditions, including higher temperatures, higher pressures and limited liquid lubrication. For example, in the case of Electrical Submersible Pumps (ESPs) in oil wells, which typically have 10 years or longer productive life [6], replacing of the ESP is a time consuming and expensive procedure, associate with oil production loss [7]. The thrust bearing in ESP's seal chamber and electrical motor could fail because of excessive load, vibration and high temperature [8,9]. So it is important to research and implement new bearing materials, which could sustain higher loads and higher temperatures, and potentially extend ESP service life and reduce maintenance costs.

PTFE exhibits outstanding properties such as low coefficient of friction, high ductility, broad working temperature, anti-seizure properties and inertness to chemicals. These properties make PTFE an efficient substitute for white metal in tilting-pad thrust bearings [5,10,11]. Using laboratory experiments and finite-element analysis, Glavatskih and other researchers examined the application of PTFE-faced hydrodynamic thrust bearings [12–15] and found that PTFE composites have good thermal insulation so that pad thermal crowning is reduced. This allowed them to operate with lower power loss, and slightly higher collar temperatures, compared with similar Babbitt bearings. Besides these advantages, PTFE based composites showed much better wear resistance compared to Babbitt [3,16]. The PTFE composites on the PTFE-faced pad are in bulk form, with a thickness of over 1 mm.

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However, polymers typically exhibit higher thermal expansion, and thus thick polymer materials can not be applied in high precision conditions, such as journal bearings, which need to retain high dimensional stability. These problems could be addressed if the polymer is in a thin layer coating on a metal substrate, in which case dimensional stability and conventional bearing clearances are retained [17]. Also, using thermo-elasto-hydrodynamic (TEHD) analysis of thrust bearings with PTFE-faced pads, Fillon showed that a decrease of the PTFE layer would help increase the oil film thickness and decrease oil film maximum temperature [5].

Despite the published research on the application of polymer materials on hydrodynamic bearings, the literature is scarce for thin polymeric-based coatings in hydrodynamic bearings. Since PTFE and other polymer materials show cold creep and high wear rate in pure format, researchers have tried to improve their tribological performance by adding different fillers and reinforcements in pure polymers [3,16,18–23]. PTFE-based, PEEK-based and ATSP-based bulk materials as well as thin (10's of micron thick) coatings were shown to improve the tribological performance in air-conditioning and refrigeration compressors [22–24]. In this work, three different metal-backed thin coatings, which all included PTFE, were procured and tested under conditions of thrust tilting-pad bearing, which are representative of hydrodynamic bearings. The tribological performance of these coatings was investigated under boundary lubricated pin-on-disc experimental conditions, simulating extreme working conditions of the tilting pad thrust bearing in ESPs. It is acknowledged that coating resistance to abrasive particles and high temperatures encountered in ESPs are also critical, and will be studied in a future publication.

2. Experimental

2.1. High pressure tribometer (HPT) and experiment configuration

Fig. 1(a) shows a photograph of the HPT, and the simulated pin-on-disc configuration is depicted in Fig. 1(b). It has the following capabilities: closed loop normal load control up to 4500 N; environmental chamber pressure control from 0.0014 MPa to 1.72 MPa; closed loop temperature control from −10 °C to 120 °C; measures in-situ friction force, normal force, and near contact temperature; and performs unidirectional and oscillatory experiments. Hydrodynamic bearings are most prone to failure during transient operating conditions, especially at the stop/start stage [16,25]. Shown in Fig. 1(c) is a schematic of a tilting pad thrust bearing, under extreme working conditions such as high load, stop/start, lack of lubrication or vibration, in which case the tilting pad and the runner contact each other.

The boundary lubricated pin-on-disc experimental configuration simulates these severe conditions. The disc is made out of the bearing pad material, and the pin from the collar material. The disc was mounted on the upper rotating spindle and the pin was fixed on the pin holder, which is directly attached on a 6-degrees-of-freedom force transducer. Normal load and rotation of the disc were input parameters to test the tribological performance of the disc and pin.

2.2. Samples

Three commonly used tilt pad body materials were selected as disc substrates, namely 304 stainless steel, copper chrome C182000 (denoted as C182), and tin bronze C932000 (denoted as C932). 4130 steel was selected as the collar material, which was made to the counter pin material. Three coatings, namely ATSP based, PEEK based and PTFE based were deposited on the pad body materials C182 and C932. The coatings were not coated on the stainless steel substrate because stainless steel showed the worst performance when tested against 4130 steel.

Two types of oligomeric system, namely CB2 and AB2, which have carboxylic end groups and acetoxy end groups, are the precursors of ATSP. The detailed description for the synthesis of ATSP powder can be found in Ref. [26]. The ATSP powder was ground and sieved to obtain fine particles not to exceed a maximum size of 90 µm. Then the ATSP powder was blended with PTFE powder (Zonyl® MP1100, DuPont®), which works as an additive to reduce the coefficient of friction. Electrostatic spray deposition (ESD) method was applied to spray the blended powder on the sand blasted C182 and C932 disks. Then the disks were cured under 270 °C for 30 min in an oven with convective air. The final thickness of the ATSP coating was around 40 µm.

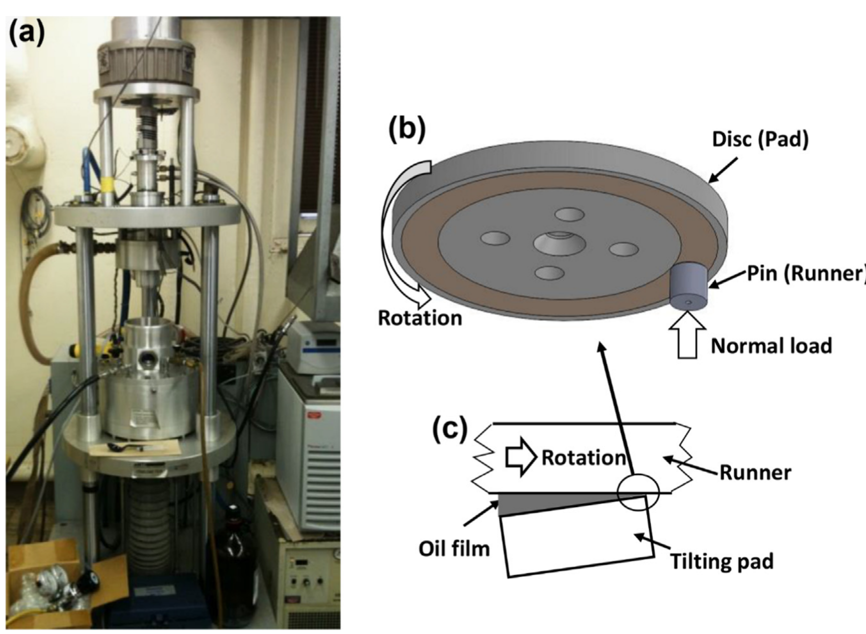

Fig. 1. HPT and experiment configuration, (a) photograph of the HPT, (b) schematic of pin-on-disc configuration, (c) thrust tilting pad bearing.