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Technical note

Seawater lubricated polymer journal bearings for use in wave energy converters

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A R T I C L E I N F O

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A B S T R A C T

This study investigates the wear characteristics of polymeric journal bearings while immersed in seawater, and their applicability towards wave energy conversion. A block on ring wear machine was used to test four commercially available bearing materials under unidirectional and oscillatory sliding conditions at low pressure. It was observed that wear generally increases with counterface roughness; however, major deviations to this trend exist, depending on the bearing's composition. Stable wear rates were shown to vary widely depending on velocity profile, though a general trend could not be established for the sample group as a whole. It was shown that polymer wear rates cannot be attributed to any one parameter, and that detailed testing at several characteristic pressures and velocities is needed to determine a material's applicability towards wave energy converters operating in real seas.

1. Introduction

In a world with ever-increasing energy demands, and a necessity to produce energy from clean and sustainable sources, much research and development is being conducted in the area of wave energy conversion. Wave energy converters (WECs) extract the incident energy of the ocean's waves into usable power which is typically transmitted to shore via underwater cables. The worldwide resource is estimated to be approximately 2 TW, with about 10%–25% being economically extractable [1]. With 75% of the world's population projected to live within 200 km of the coast by 2025, offshore power production is becoming increasingly more important [2].

One of the most challenging aspects of wave energy conversion is the extreme environments and conditions which WECs must be designed to operate in order to extract energy from the most energetic wave climates. With maintenance on these ocean structures often impractical, impossible, or prohibitively expensive, design for reliability is paramount to the success of the wave energy industry. If wave energy is to be an economically viable resource, WECs must be designed to be both reliable and survivable [3].

One aspect of WEC design that has proven problematic is bearing design. Point absorbing WECs are primarily designed to harvest the heave motion of a passing wave, which causes relative motion between two or more bodies. Common architectures harness this motion linearly or rotationally, which is used to drive a power take-off. With WECs expected to be subjected to up to 5000 h operation and 8400 km bearing sliding distance per year in some climates [4], a robust bearing system is required to provide a reliable and low maintenance running surface for WEC components.

Most WECs are designed with at least one moving part either fully submerged or in regular contact with seawater, which due to effects such as corrosion and biofouling, can render most traditional solutions such as ball and roller bearings impractical. Complicated lubrication systems like the ones used in stern tubes of ships are also undesirable due to environmental effects of shaft lubricants, increased maintenance, and parasitic pumping requirements. Polymer-based journal bearings have been identified as a possible solution to this problem due to their simplistic nature, and their ability to provide a corrosion-resistant, low friction, low wear running surface.

Whereas some traditional journal bearings rely on externally supplied lubrication such as grease or oil to prevent wear of sliding components, polymer-based bearings provide self-lubrication by depositing a thin transfer film of the bearing material onto the counterface [5]. The deposited transfer film serves three primary purposes: to reduce the effect of the surface roughness of the counterface by filling in the surface asperities, thereby reducing the removal of more bearing material by the asperity peaks [6], to provide self-lubrication, and in some cases to reduce friction [7]. One of the biggest obstacles to the implementation of polymeric bearings in a marine environment is the ability of salt water to

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Table 1
Details of the materials investigated in this study.

Product	Type	Composition/Details
Orkot TXM Marine	Fabric Reinforced	PTFE woven Polyester ID, with MoS_2 and PTFE lubricants in the subsequent wound layers
Tivar 1000	Homogeneous	Ultra High Molecular Weight Polyethylene (UHMWPE)
UC300	Fabric Reinforced	Woven polyester composite with PTFE lubricant
UC400	Fabric Reinforced	Woven polyester composite with MoS_2 lubricant

inhibit or prevent the formation of transfer films on the counterface by washing away the deposited layers, which can drastically increase the wear rate of the material [8]. In one experiment, wear was higher in water than air for 25 of 25 materials considered [9]. It is critical to choose a bearing/counterface tribosystem which permits the formation of transfer films in salt water in order for polymeric bearings to provide a reliable, robust solution for WECs.

Since most of the literature available on this topic is concerned with high-load, low speed applications in air and fresh water, this study intends to serve as an assessment of several commercially available materials in seawater. While WECs operating in real seas will experience widely varying PV loading depending on incident wave conditions, this study assesses wear at one characteristic PV in order to provide a viewpoint on the wear mechanisms of twelve different bearing/counterface combinations. In order to determine the effect of velocity profile on wear rate, both sinusoidal and constant velocities were tested. A velocity and bearing pressure were chosen which represent a typical loading scenario of a WEC in regular waves in the open ocean.

In reality, bearing wear can be attributed to many things, such as chemical reactions at the counterface surface, and polymer chain crystallinity and formation, and a vast array of other phenomena; however, such effects will not be considered here. The focus of this study will be the mechanical removal of bearing material by the counterface, and the effect of internal lubricants and composition on the steady state wear. This paper does not purport to identify one "best" bearing for use in wave energy converters, but attempts to provide information and design guidance to WEC developers who are considering testing or using these components.

2. Experimental setup and methods

2.1. Bearing materials

The materials examined in this study are outlined in Table 1. Three of the four materials are mandrel-wound fabric reinforced bearings, and were chosen due to differences in their composition. The fourth material is a homogenous material made of ultra high molecular weight polyethylene (UHMWPE). All of the bearing materials used in this study were obtained commercially, and are standard stock sizes. Photos of the bearing samples can be seen in Fig. 1.

The bearing samples were machined to dimensions 15.75 mm in length, 6.35 mm wide, and about 10 mm in height, with the bottom surface having the same radius as the counterface. The inner running surface of the mandrel-wound bearings remained unmachined in order to preserve the original characteristics of the material. The bearing samples were machined in this manner due to differences in the mechanical properties of fabric-reinforced bearings produced on a mandrel versus those produced as pressed sheet. Since the maximum pressure that can be applied to a mandrel-wound bearing during curing is dictated by the tensile strength of the fibers as they are wrapped around the form, the mechanical strength of wound bearings differs from sheet bearings. Sheet bearings are cured under high mechanical pressure, which typically gives them greater mechanical strength normal to the fibers. Current ASTM testing standards do not address this difference, and little is known about the tribological differences. An added benefit to bearing samples of this shape is that the pressure remains constant throughout the test. This is possible since the contact area between the bearing and counterface does not change with vertical wear.

Special care was taken to avoid any tearing or delamination of the fabric reinforced bearings on the bearing running surface. Small machined ends of the fabric commonly remained on the outer edges of the sample, but did not affect the wear of the material as they were not in significant contact with the counterface. In order to maintain similarity in the shape of the samples, Tivar was machined to the same shape. Special care was taken to avoid burring and melting by keeping the material cool by spraying with compressed air when in contact with the cutting tool. Samples were cleaned with methanol prior to each test.

2.2. Counterfaces

Adhering to manufacturer recommendations, 316 stainless steel was chosen as a counterface for the first three tests in this study. Super-polished stainless steel counterfaces of 0.1 μm roughness average (RA), and 316 counterfaces polished to a typical manufacturer specifications (spec polished) of 0.3 μm RA were used. After each test, any deposited bearing material was removed, and the wheels were re-polished to be used again in subsequent tests. Polishing (or roughening) was conducted perpendicular to the direction of rotation of the counterface, as suggested by Marcus

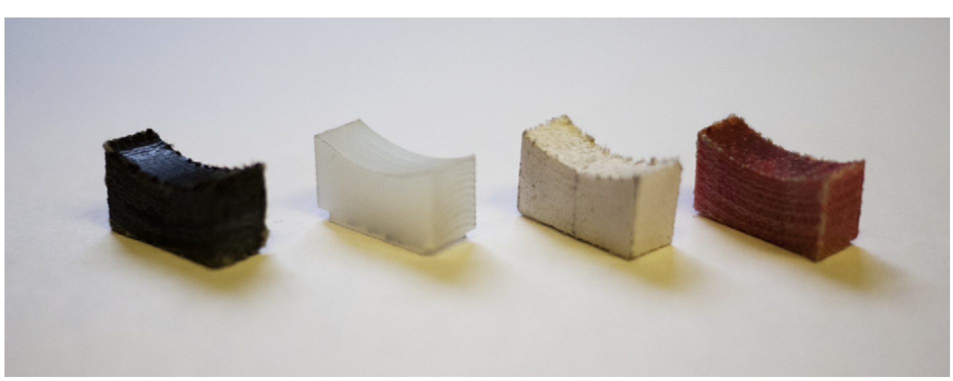

Fig. 1. Photo of samples used in this study, left to right – Orkot TXM Marine, Tivar 1000, UC300, UC400.