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Case study

Tribological behavior of polyamide-6 plastics and their potential use in industrial applications

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ABSTRACT

The present research article addresses an investigation of tribological properties of 3 commercially available cast polyamide 6 (PA 6): a natural PA 6 polymer, a PA 6 filled with molybdenum disulfide (MoS_2), and a PA 6 filled with a special solid lubricant. In order to analyze the potential use of these materials in industrial applications, their tribological results were compared with those measured for a commercial bronze alloy. All materials (including the bronze alloy) were subjected to sliding against a steel SAE 1020 disc in a tribometer. Three different types of tribotests were carried in this study: (i) wear tests, (ii) PV (pressure × velocity) tests, and (iii) stick-slip tests. Optical microscopy was employed to characterize the wear mechanisms of the materials selected in this study. PA 6 filled with special solid lubricant revealed superior tribological properties among the plastics, since it has shown the lowest coefficient of friction (COF), and the highest wear resistance and PV limit. PA 6 filled with the special solid lubricant also exhibited lower stick-slip oscillations than the PA 6 filled with MoS_2. Micrograph analysis revealed abrasion as the most important wear mechanism for the PA 6 filled with the special solid lubricant. On the other hand, severe damage was observed on the surface of the natural PA 6 and the PA 6 filled with MoS_2 in the wear tests. Bronze alloy exhibited the highest wear rate among the materials studied in this work. Adhesion was the dominant wear mechanism for this metal.

1. Introduction

The use of polymers and polymeric composites in seals and bearings and other industrial applications where tribological properties are important is growing rapidly [1]. Plastic and composite materials are commonly employed in engineering applications as alternative to traditional metal materials due to their good mechanical and tribological properties and also light weight [2]. One of the most often used engineering plastic is the polyamide 6 (PA6) because of its quite good mechanical (strength, hardness, toughness, damping) and tribological (sliding, wearing resistance) characteristics [3,4]. Due to this, it is also used as bearing bushes, wearing laths, pulleys, gears, etc [4]. For such applications, reinforced compounds and additives are used in order to increase the performance of the polymer materials. The additives can be classified according to their function as antistatic, fillers, lubricants, fire resistant and antioxidation agents [5]. Examples of lubricating additives are polytetrafluoroethylene (PTFE), silicone fluids, carbon fibers, graphite, molybdenum disulfide, and metallic powders [3].

Information about the tribological behavior of additivated polymers is limited in the scientific literature. Also, plastic and composite manufacturers do not provide complete information about the wear and friction performance of the materials they produce. In the cases where the polymer manufacturer provides some tribological data from their materials, these data are the result of limited tests, which may not represent an actual application. As reported by Silva, 2010 [6], friction and wear are very unique properties obtained for the tribosystem in which they are measured. For this reason, in order to better represent the tribological results of a material, it is necessary to consider various parameters, such as the topography and geometry of the mating materials, type of motion (rolling, sliding or alternative motion), operating conditions (temperature, pressure, velocity, etc.), and others. Laranjeira, 2011 [7], have a similar understanding of this issue. According to the author, to obtain a precise tribological result, friction and wear performance of the materials must be measured under the same operating conditions than those found in their actual application.

The propensity that a given polymer has to produce stick-slip

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motion when it slides against a metal counterpart is another data rarely found in literature. According to Van de Velde and De Baets, 1997 [8], a proper bearing material used to positioning has to exclude stick-slip and should behave well during stop-restart conditions. The researchers also added that PA 6 sliding against steel is sensitive to stick-slip motion, which complicates accurate positioning.

The aim of the present work is to investigate tribological properties of 3 commercially available cast polyamide 6 (PA 6). Friction and wear performance was measured in wear tests, which were designed based on the operating conditions of an actual engineering application, i.e. a shaft-bearing system. Experimental work carried out in the present study also included to determine the PV limit, as well as to measure stick-slip motion resulting from tests performed using the additivated polymers. The wear and friction performance obtained in the wear tests were compared with those obtained for a bronze alloy, which is a traditional metal used as bearing bush.

2. Experimental procedures

2.1. Materials

Three engineering plastics and a bronze alloy were used as specimens in the present investigation. All the three plastics selected in this study are commercially available cast polyamides (PA 6), produced by Ensinger GMBH (Germany). The specimens are distinguished by the type of solid lubricant, as following: (i) a natural PA 6 polymer (TECAST T), which is white; (ii) PA 6 filled with MoS_2 (commercial name: TECAST T MO Black), which is black; and (iii) PA 6 filled with a special solid lubricant (TECAGLIDE Green), which is green. According to information provided by the manufacturer [9], TECAGLIDE Green is a high performance plastic. The metal specimen is a bronze alloy, which is commercially known as TM 23. Table 1 shows the mechanical properties of the plastics selected in this study.

All materials (including the brass alloy) were subjected to sliding against a steel SAE 1020 disc in a tribometer. This disc has a diameter and thickness of 159 mm and 12 mm, respectively. Before each test, its surface was sanded with sandpapers of different grit sizes (280, 400, 500, 600 and 1200). A roughness Ra lower than 0.20 μm (in the radial direction) was obtained. A K-type thermocouple was embedded a distance of 1.5 mm below the disc surface, at a radius of 40 mm, which corresponds to the center of the friction track. This instrument was employed to measure the disc temperature during the tests. Fig. 1 shows the drawing and photo of the pins and disc selected in this study.

2.2. Set-up of the experiments

Fig. 2 shows the tribometer used for conducting the tribotests performed in the current study. This test rig is capable of operating under various temperature conditions (from ambient up to 600 °C), sliding velocity (from 1,8 up to 16000 mm/s), and normal

Table 1
Mechanical properties of the polymers (cast PA 6) studied in this work.

Property	Parameter	Green	Black	White
Tensile strength at yield [MPa]	Tensile test (50 mm/min)	76	80	80
Service temperature [°C]	Short term	130	170	170
Service temperature [°C]	Long term	100	100	100
Hardness [MPa]	Ball indentation	159	170	170
Modulus of elasticity [MPa]	Tensile test (1 mm/min)	3200	3200	3500

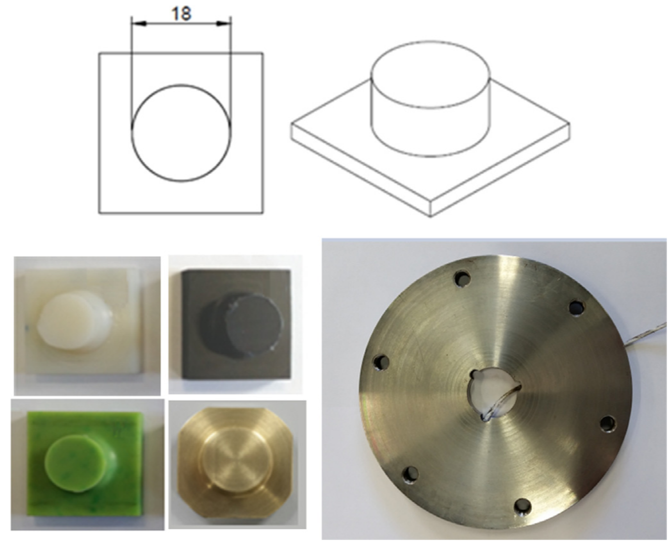

Fig. 1. Drawing of the pins (above), and photos taken from the materials (at left-below) and steel disc (at right-below) selected in this study.

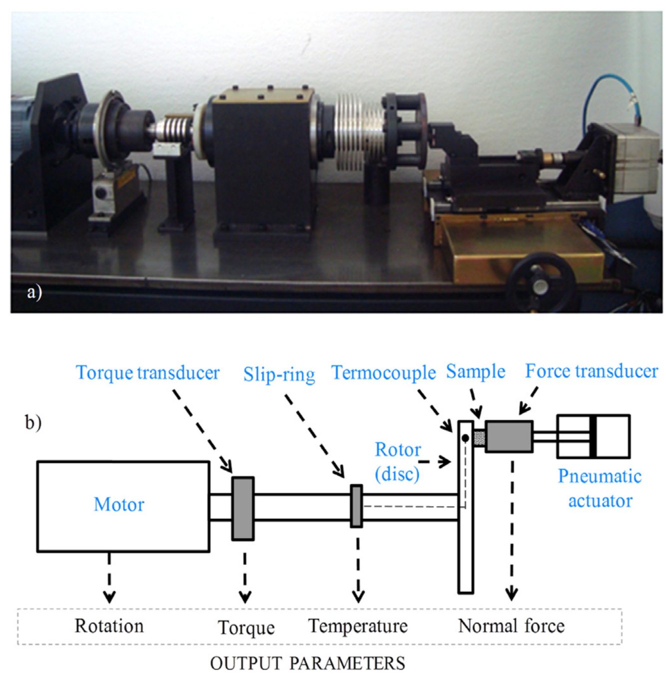

Fig. 2. Tribometer used in the tribotests: a) digital photograph and b) schematic.

force (from 0 up to 2500 N). Due to the ability to perform very low speed tests, the laboratory-scale tribometer is able to measure friction induced oscillations (stick-slip) resulting from the rubbing contact materials, as shown in some earlier papers [10–12].

In the laboratory-scale tribometer, the coefficient of friction is calculated by an indirect measurement method, which considers the relationship given by the Eq. (1). Repeatability (precision) of the friction measurements performed by the tribometer is ± 0.013, as shown in [13]. Besides, a previous study of the present research group has shown that the friction results provided by the laboratory-scale tribometer are in good agreement with the measurements obtained in a standard pin-on-disc tribometer [14].

$$\mu = \frac{T}{F_N R} \quad (1)$$

where T is the torque, F_N is the normal force exerted by the pin on