Wear 338-339 (2015) 418–421

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Friction measurement method and modeling of a metallic rod sliding through a flexible polymer tube

T.J. Turner, J.M. Gorman*, E.M. Sparrow

Department of Mechanical Engineering, University of Minnesota, Minneapolis, MN, USA

ARTICLE INFO

Article history:
Received 24 February 2015
Received in revised form
31 July 2015
Accepted 4 August 2015
Available online 10 August 2015

Keywords:
Annular tribometer
Sliding centerbody
Stationary sleeve
Stainless steel 316
Silicone tubing
Sliding friction

ABSTRACT

A new tribometer has been developed for the measurement of sliding friction between a stationary flexible polymeric sleeve and a rigid metallic rod that moves longitudinally within the sleeve. The tribometer enables both the normal and pull forces to be controlled and measured to high accuracy. The pull force was provided by an adaptation of a tensile testing machine which imparts a precisely controlled linear motion to the sliding tribopartner. Direct measurement of the normal force at the interface between the tribopartners is not necessary since it can be determined to very high accuracy by the innovative use of numerical simulation. Prior to its application to a specific physical situation, numerous replicate experiments were performed which demonstrated virtually perfect reproducibility. The tribometer was applied to determine the relationship between the extent of plasma processing of the bore of a flexible polymeric tube and the coefficient of friction between the tube and a stainless steel rod sliding within the silicone tube. This situation frequently arises in connection with therapeutic biomedical devices. The coefficients of friction determined from the experiments displayed a monotonic decrease as the extent of processing increased.

1. Introduction

There is a well-established need for accurate measurements of sliding friction between tribopartners, where one is rigid and the other is more flexible. In the situation of interest here, this need is illustrated by a metal rod sliding through a flexible polymeric tube, which is a common configuration in biomedical devices. A literature search performed to identify prior work involving this type of tribopartner configuration – a rigid rod sliding in a flexible polymeric tube. The search included the possible identification of any tribometers that might be capable of measuring sliding friction for the metal-rod-in-polymer-tube system.

A large number of papers was found which dealt with friction and wear between polymer and metal tribopartners, but in no case would the participating tribometers be capable of dealing with the rod-in-tube configuration. To support this conclusion, it is relevant to note that for a representative sample of 10 papers, a pin-on-disk device was utilized in [1,3,6,7,9], a ring-on-disk device in [4], pin-on-flat in [5], flat-on-flat in [10], squeeze plates in [2], and sphere-on-plate in [8].

The development of a novel tribometer suitable for the system consisting of a metal rod sliding in a stationary polymeric tube is the focus of this paper. The development of the instrument constitutes the first part of the paper. The second part of the paper is a combined laboratory experiment and numerical simulation which demonstrates the capability of the instrument.

2. Methods and materials

2.1. Description of the tribometer

For the accurate determination of the coefficient of sliding friction, the most critical values are the normal force imposed on the moving metallic tribopartner (by the surrounding polymer sleeve) and the longitudinal force needed to move it parallel to its axis at a constant velocity. The instrument that was designed and fabricated to provide the needed measurements will now be described by means of Fig. 1.

The figure shows an exploded view of the instrument. When used for the actual experiments, the major components are held tightly together by torqued screws. As can be seen in the figure, the test section is a circular groove in the assembled structure. The groove houses the sliding metallic rod, the polymeric annular sleeve, a second annular sleeve which serves to apply pressure to the tribopartners, and an annular space into which pressurized air is ducted. Note that provision has been made to seal the ends of the test section by means of O-rings. Not shown but present are

* Corresponding author.
E-mail address: gorma157@umn.edu (J.M. Gorman).

http://dx.doi.org/10.1016/j.wear.2015.08.001
0043-1648/

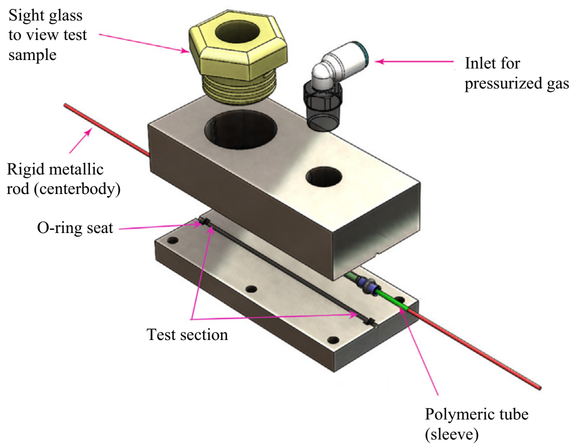

Fig. 1. Exploded view of the main portion of the tribometer. (For interpretation of the references to color in the text reference to this figure, the reader is referred to the web version of this article.)

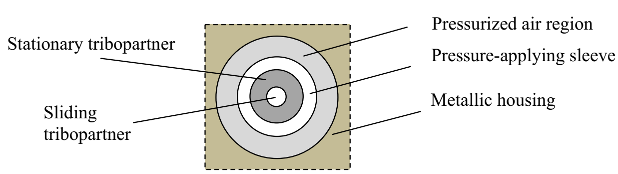

Fig. 2. Cross-sectional view of the tribometer at any location that is away from its ends.

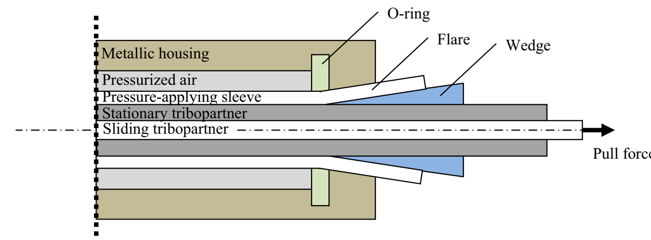

Fig. 3. Longitudinal schematic of one end of the tribometer.

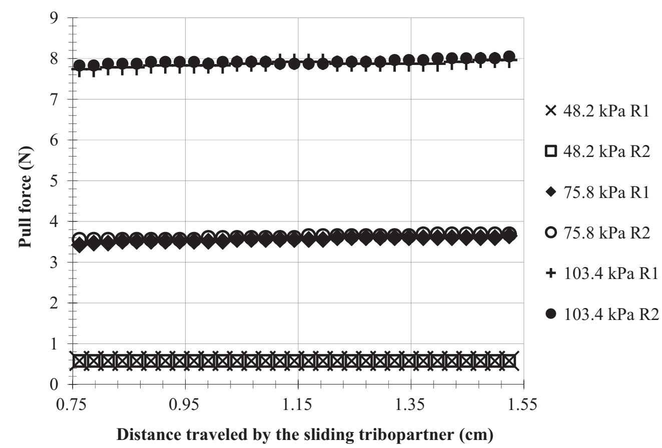

Fig. 4. Replicate data runs to demonstrate reproducibility. Three different applied external pressures were selected and two replicate runs for each pressure were implemented.

strips of O-ring material that flank the test section on either side as a failsafe defense against transverse leakage. The diagram highlights the sliding centerbody in red and the stationary polymeric tribopartner in green.

To provide a more in-depth description of the tribometer, Figs. 2 and 3 have been prepared. These figures respectively show cross-sectional and longitudinal views of the instrument.

As seen in Fig. 2, the participating components are axisymmetric and share a common axis. They are, in order of increasing radial location: (a) the sliding metallic tribopartner, (b) the stationary polymeric tribopartner, (c) a polymeric sleeve whose function is to apply a circumferentially and longitudinally uniform pressure, and (d) a hermetically sealed pressurized annular space. The components are not necessarily drawn to scale. In practice, it was found beneficial to sheath the flexible tribopartner by a second polymeric tube and to apply air pressure to the external surface of the sheathing tube. The advantage of using a sheathing tube is that its ends could be mated with O-rings without disturbing the system proper. The dimensions of the various components pictured in Fig. 2 are: (a) stainless steel metallic tribopartner, diameter = 1.03 mm, (b) silicone tribopartner, inner diameter = 1.07 mm, outer diameter = 1.32 mm, and (c) silicone pressure-applying sleeve, inner diameter = 1.73 mm, outer diameter = 2.29 mm.

It can be seen in Fig. 3 that the end of the pressure-applying sleeve is flared (by application of heptane) to receive a wedge placed between the flare and the stationary tribopartner. The flare presses on the bore of an O-ring which is seated in the test-section groove in the metal housing. This arrangement is both absolutely stable and leak free. The gauge pressures contained in the air-filled annulus ranged from 20,700 to 103,400 Pa.

Controlled vertical motion of the sliding tribopartner was achieved with the aid of a MTS Synergie 200 system (MTS Systems Corp., Eden Prairie, MN). The system is equipped with a calibrated 50 N load cell with an accuracy of 0.01%. Accompanying software post-processes the acquired data for displacement versus pull force. The software was programmed to pull the sliding tribopartner at a rate of 1.27 cm/min for a displacement distance of 1.27 cm. The output of the post-processing performed by the MTS system is the force attributable to the sliding friction. This force is one of the two inputs needed to determine the coefficient of friction. Coupling between the exposed end of the sliding tribopartner and the MTS system was achieved by means of a Jacobs drill chuck.

To determine the normal force which is the other input to the calculation of the coefficient of sliding friction, it is essential to know the pressure applied at the interface of the stationary polymeric tribopartner and the moving rigid tribopartner. In this regard, the only directly measured pressure is that in the pressurized air annulus (see Fig. 2) situated external to the tribopartners. The pressure in that annulus is controlled by a high-precision digital pressure switch series ISE40, SMC Corporation of America, Noblesville, Indiana 46060. The stated pressure resolution is 0.69 kPa.

To assess the quality of the tribometer, a series of experimental runs were performed to demonstrate reproducibility. For this purpose, three different externally applied pressures in the air annulus were employed, and two replicate runs were carried out for each of these pressures. The corresponding pull forces were determined, and the results are presented in Fig. 4. It can be seen from the figure that excellent reproducibility was obtained, and this outcome offers strong support for the quality of the tribometer.

Although the externally applied pressure delivered to the air annulus (Fig. 2) is measured to very high accuracy, the pressure that is actually applied to the surface of the moving tribopartner is not necessarily known. The relationship between the pressure in the air annulus and that applied to the surface of the moving tribopartner is most effectively determined by numerical simulation.