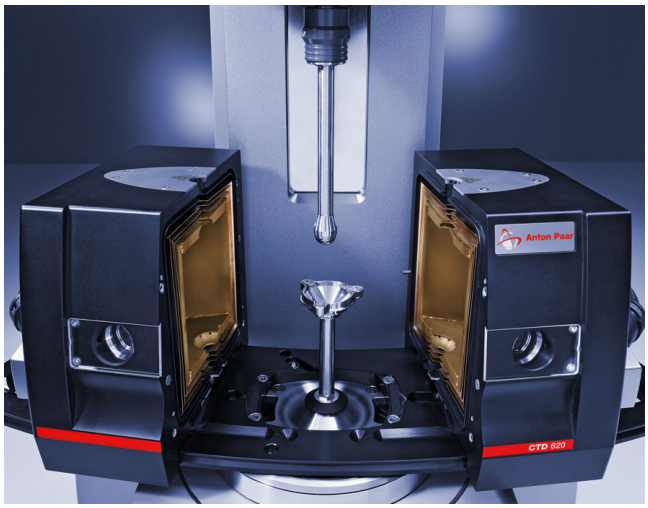
New Approach for Accurate Determination of Influence of Humidity on Static Friction between Polymer-Steel Tribocontacts

Relevant for: Tribology, Polymer Tribocontacts, Humidity

Tribological behavior of materials is strongly influenced by their surface characteristics which include roughness, chemical potential, visco-elastic properties, presence of adsorbed layers, etc. For water-absorbing materials, such as polymers, humidity strongly alters the tribological properties. In order to understand as to how these characteristics affect the tribological behavior of contacts, one requires an appropriate test and analysis methodology. Defined temperature and humidity conditions are needed to characterize tribological systems containing these types of materials. In the current report, we present a unique combination of high precision tribological testing methodology which enables the users to investigate the influence of humidity on the static friction between steel polymer contacts at model scale. This methodology can of course be extended to other relevant systems as well.



1 Introduction

Tribological behavior of materials is strongly influenced by their surface characteristics which include roughness, chemical potential, visco-elastic properties, presence of adsorbed layers, etc. For water-absorbing materials, such as polymers, humidity strongly alters the tribological properties. In order to understand as to how these characteristics affect the tribological behavior of contacts, one requires an appropriate test and analysis methodology. Defined temperature and humidity conditions are needed to characterize tribological systems containing these types of materials.

In the current report, we present a unique combination of high precision tribological testing methodology which enables the users to investigate the influence of humidity on the static friction between steel polymer contacts at model scale. This methodology can of course be extended to other relevant systems as well.

Humidity is the amount of water vapor in the atmosphere, and it can vary significantly depending upon temperature, geography, weather, altitude, etc. Humidity is generally expressed in the form of percentage relative humidity (%RH) which is the ratio between partial pressure of water vapor in an air-water mixture to the saturated vapor pressure of water at a given temperature.

An example from everyday life, where level of humidity could possible influence friction behavior is a touchscreen. While swiping a finger on a touchscreen, one can notice the difference in the force applied to the finger to initiate motion as well as keep it in motion depends whether or not the hands are sweaty.

Of technical relevance are the humidity dependence of advanced materials and coatings, like for example DLC coatings or polymer components (ABS, nylon, polycarbonate, etc.). We expect components featuring these materials to perform well in the outback of Australia, as well as in humid Singapore. Therefore, for optimizing performance, efficiency, or even the feel of materials and systems at different humidity levels, model scale tribometric investigations can offer a quick and reliable means of evaluating and understanding the tribosystem of interest.

Detailed description regarding static friction and its determination with the help of MCR Tribometer can be found in the following application report [B74IA007EN-A]

2 Test Setup

The tests were carried out on a Modular Compact Rheometer from Anton Paar, see Figure 1. The rheometer was equipped with a convection temperature device, Humidity Ready. The chamber of this device is so designed to facilitate precise control of temperature and at the same time regulate the atmosphere - humidity, gases, etc. - around the test specimen. Illustrations of the CTD chamber along with the ball-on-three-plates test configuration are provided in Figure 2. Herein, the three plates are fixed in the specimen holder while the ball is fixed on to the measuring shaft. During the test, contact between the ball and the plates is established by lowering the measuring shaft, while the specimen holder with the plates aligns itself for equal force distribution on the plates.

Humidity in the CTD chamber was constantly regulated and monitored with the aid of a Modular Humidity Generator from Proumid (www.proumid.com), which is shown along with the MCR Tribometer in Figure 1. This equipment enables fast and accurate humidity control with the possibility of integrating the humidity values during real time test data acquisition.

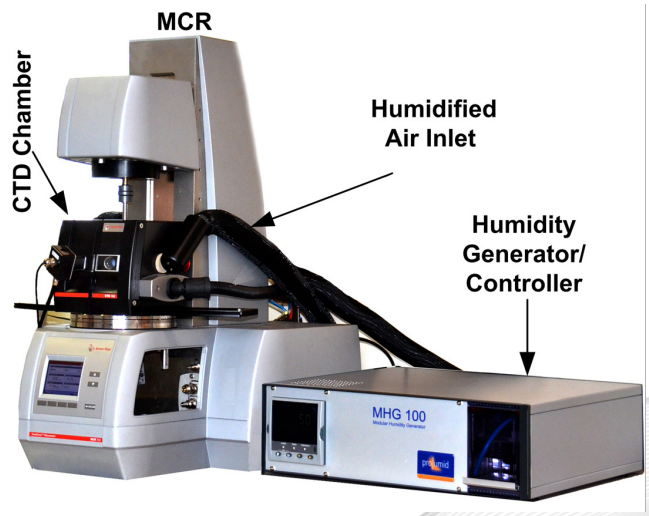


Figure 1 Modular Compact Rheometer MCR 702 from Anton Paar along with Modular Humidity Generator MHG 100 from Proumid.

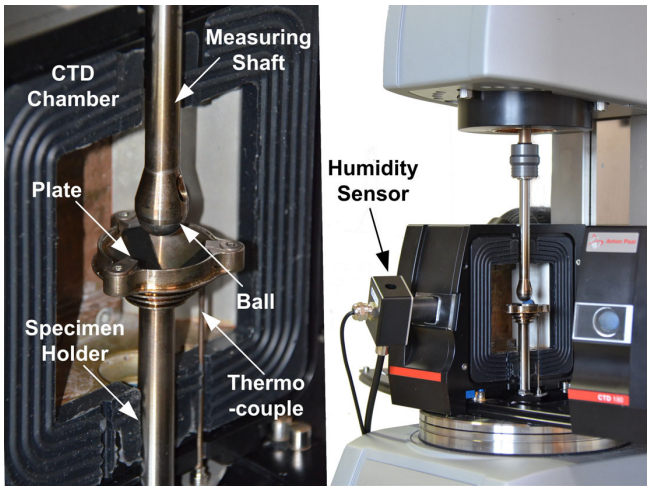


Figure 2 Detailed illustration of the CTD Humidity Ready chamber and the ball-on-three-plates test configuration.

2.1 Test Principle

Determination of limiting friction and the break-away torque values of a system involve a simple principle. When at rest, the static friction between the bodies inhibits any relative motion at macroscopic scale, unless acted upon by an external force which exceeds this frictional resistance. Therefore, the applied force, in this case, the torque applied to the motor which in turn rotates the measuring shaft, is gradually increased and the resulting deflection or the sliding distance is measured. At the moment the applied forces exceed the break-away forces, the system shows a sudden and substantial increase in the displacement of the shaft. While the principle in itself is simple, its execution requires precision control of the applied forces as well as the being able to observe and record changes in the deflection angle of the shaft in nano- to microscale. MCR Tribometers from Anton Paar offer the perfect combination of all the above features.

2.2 Test Profile

The tests comprised of three phases. i.e., initial contact phase, loading and holding phase, and the torque ramp phase, see Table 1. During the initial contact phase, as the name suggests, the measuring shaft is lowered until the ball comes in contact with the plates. The maximum load attained during this initial contact is restricted to 0.1 N. This is done to avoid shock loading or sudden impact on the surfaces. In the second phase, the load is then gradually

increased until the tribological normal force ($F_{N,\ Tribo}$)[1])reaches the predetermined value of 5 N. The system is then held at the test load for the next 15 minutes. The stresses produced by the load at the contact are partially relaxed during this step. In the third phase, the torque is increased logarithmically from 0.01 to 50 mNm, see Figure 3.

Step	Description	Parameters	
		$F_{N,\ Tribo}$ [N]	Duration [min]
1	Initial Contact	0.1	1
2	Holding at Test Load	5	15
3	Torque ramp from 10^{-2} to 50 mNm	5	10

Table 1 Test Profile

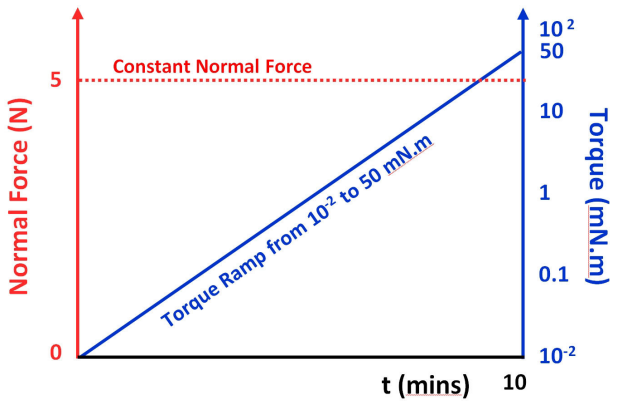


Figure 3 Schematic of the torque ramp.

2.3 Specimen

The set of specimen for each of the tests consisted of one ball and three plates, hence the name ball-on-three-plates. The material used for the specimen is provided below in Table 2. Surfaces of specimen were cleaned with isopropanol just before starting the test to remove dirt and other organic substances. No additional lubricant was used in the tests.

Ball (Ø 12.7 mm)	Plates (6 mm x 15 mm x 3 mm)
Steel (1.4401)	Polyoxymethylene (POM)
	Polyamide 6.6 (PA6.6)

Table 2 Details of the Specimen Used in the Tests.

3 Results

The results are presented below in form of graphs wherein the sliding distance is plotted as a function of increasing torque. Figure 4 represents characteristic curves for POM-steel and PA6.6-steel combination. For the sake of clarity, only data corresponding to torque values greater than 1 mNm are presented here.

The break-away points in each of the curves in Figure 4, indicate the starting point of macroscopic motion of the ball against the plates. Until that point, the increase in the sliding distance with increasing torque is in the sub-micron to micron range. This change can be attributed to the elastic and plastic deformation of the system prior to the onset of macroscopic motion. Once the applied torque reaches the break-away point, the sliding distance shoots suddenly from a couple of micrometers to a few millimeters. This shift in the sliding distance by three orders of magnitude indicates the onset of sliding motion between the ball and the plates. The coefficient of friction recorded at the break-away point corresponds to the limiting friction of the system.

For both systems studied here, the break-away torque is seen to increase with increasing humidity. The difference however is more significant in the case of PA6.6-steel interface as compared to POM-steel contact. PA6.6 is more hygroscopic as POM. The stronger increase of absorbed water also alters the tribological properties more severely.

The average of three test values of break-away torque and limiting friction for each of the systems at each level of humidity is summarized in Figure 5.

[1] Tribological Normal Force: Force acting normal to the contact, deduced from the contact geometry

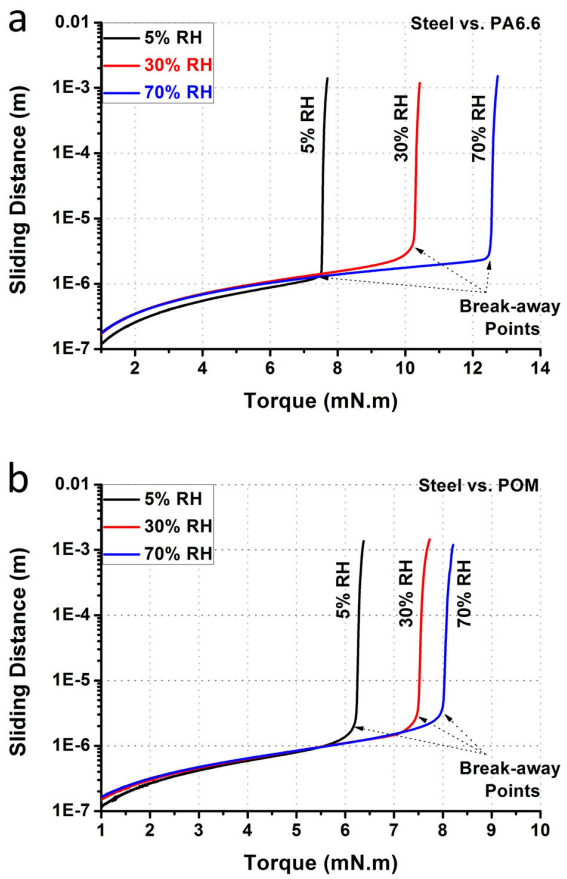


Figure 4 Plots depicting sliding distance as a function of torque for (a) POM-steel and (b) PA6.6-steel tribopairs. The torque value at the break-away points corresponds to the break-away torque of the system.

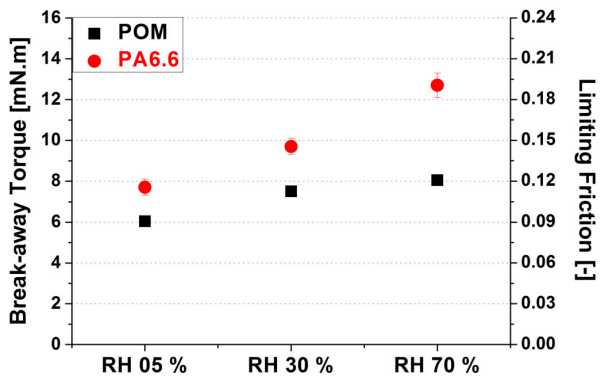


Figure 5 Break-away torque values along with limiting friction coefficients of POM-steel and PA6.6-steel systems.

4 Summary

Tribometric tests were carried out on two different tribosystems - POM-steel and PA6.6-steel - to study the influence of humidity on their static friction behavior. Results show that with increasing humidity, the limiting friction of at the contact increased for both systems.

Additionally, the tests also have shown that MCR Tribometers, combined with MHG 100 Humidity Controller, offer a unique possibility of studying the influence of humidity on tribological characteristics of a system with high precision. The results also showed exceptional reproducibility. The other advantage of the setup is that the humidity levels in the test chamber can be regulated quite quickly and with ease.

Typical fields of application for this methodology are the automotive industry, healthcare and beauty products (contact lenses, lipsticks, etc.), polymer industry, electronic industry, etc.

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