NOVEL METHOD FOR THE QUANTITATIVE IN-SITU DETECTION OF TRANSFER FILMS IN POLYMER-STEEL SLIDING CONTACT

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Abstract

A new method for the in situ detection of transfer films is presented. By means of an automated image analysis, the brightness of the running track and the surrounding reference area on the counter body is determined separately for the wear track and the blank counter body. It is shown how the temporal development of a polymer transfer film can be quantified and translated into numerical parameters. Furthermore, it is demonstrated how cyclic buildup and degradation processes of the transfer film correlate with the coefficient of friction and how the temperature of the counter body controls the formation of the transfer film of a selected PPS graphite composite material.

Introduction

Solidly lubricated polymer-metal sliding pairings have received increasing attention in industrial applications over the last years due to their low cost production and ease of maintenance, e.g. in sliding bearings. Furthermore, polymers are lightweight, tribologically and mechanically highly customizable and inherent resistant to corrosion.

During sliding, wear debris is released from the polymer and can be deposited on the steel surface. The resulting deposition is called a transfer film. While its name implies a homogeneous polymer layer comparable to coatings, transfer films often only consist of a collection of local depositions in the roughness grooves of the wear surface [1]. Although the coverage of the nominal wear surface with such depositions is usually low, their impact on wear and friction was demonstrated in many studies to be significant [1-4]. However, only few quantitative analysis techniques were developed over the years. Most of them observe transfer films qualitatively based on optical or electron-microscopic images [1,3,5]. Additionally, the measurement of the free-space length, i.e. the inter-deposition distance, yields quantitative data from such images [2]. Another method is the measurement of the deposition height via focus ion beam and (scanning) transmission electron microscopes [1]. Further height measurement techniques include profilometry [3], Newton's ring method [4] and Raman spectroscopy [5].

However, each element of this collection of methods lacks either quantifiable, laterally extensive, tempospatially resolved or economically viable detection of transfer films.

This study introduces a novel approach on transfer film measurement that overcomes all these issues in one method.

Experimental

Experimental setup

The presented work introduces the ratio of luminous intensity (luminosity) of the wear track and the unworn, blank steel surface as a measurable quantity for transfer films. To do so, standard consumer photographic equipment, i.e. a DSLR camera combined with a ring light, is used to intermittingly capture images of a selected section of the wear track (1/min). During this, the field of vision is chosen to include sufficient amounts of unworn steel surface. Additionally, the exposure time is matched to twice the revolution period of the steel ring. This way, the whole wear track area is captured twice on the camera's image sensor. Therefore, each image contains luminosity information from the whole wear track. Therefore, in contrast to all existing methods, this new method can reasonably be called 'laterally extensive' or even 'laterally complete'.

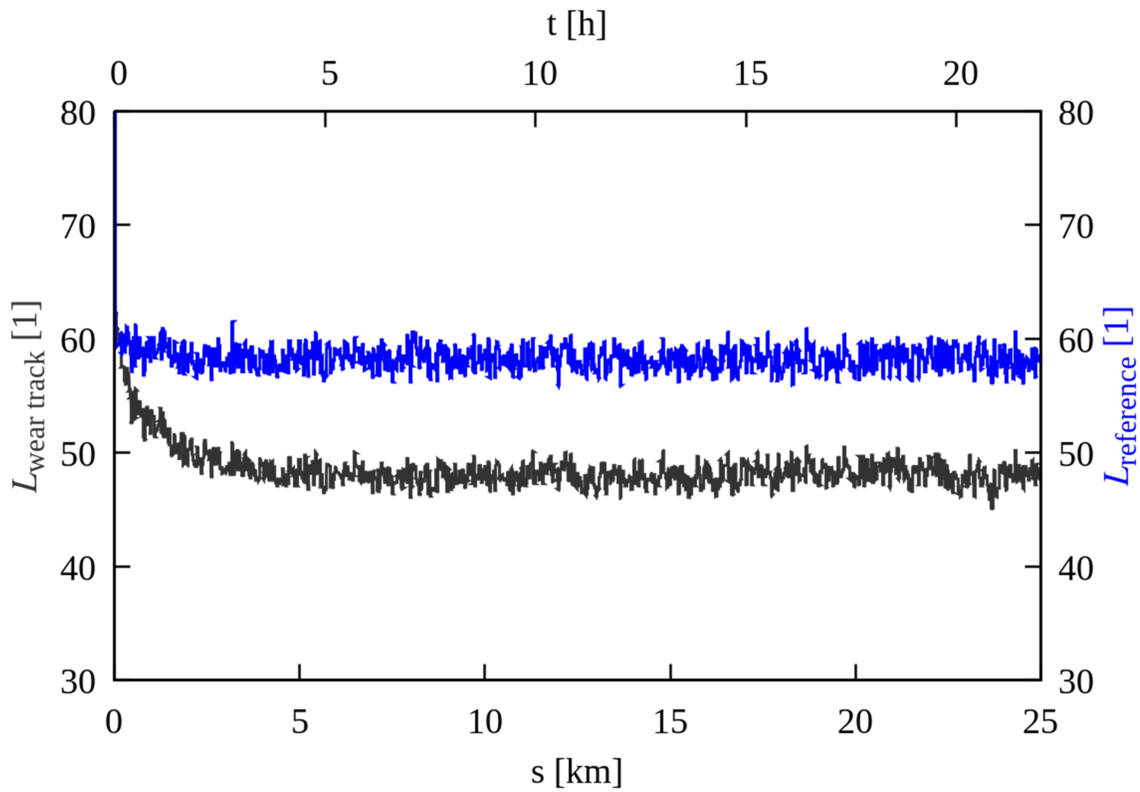

Figure 1: Absolute in-track and reference luminosities during the first test segment

This setup was implemented into a block-on-ring test rig, which complies with the ASTM G 137 testing standard. The steel ring is made of 100Cr6 bearing steel with an average roughness of 0.1 µm and a hardness of 60 HRc. The polymer block is made of Ensinger TECACOMP PPS TC black 4084, which is an industrially available PPS material filled with 30 wt.% of graphite. RGC39A graphite was provided by Superior Graphite. The initial testing parameters are 4 MPa and 0.5 m/s and the ring temperature was set to 40 ℃, which is realized by an infrared heating unit. The experiment is designed as a multi-segment test (11 segments) with a long running-in segment of approx. 122 km (68 h) and 10 subsequent segments of 10.8 km (6 h) each. In all 11 test segments, the ring temperature is alternated between 40 and 65 ℃, starting with 40 ℃ in the first segment. The objective of the first segment is to observe the evolution of the transfer film formation as well as to provide the time needed to reach a steady state. The subsequent 10 segments study the correlation between the transfer film state and the ring temperature. This test was repeated eight times to ensure statistical relevance of the obtained results.

Data processing

The obtained primary data consists of 7,680 images for each test (for a total of 61,440 for 8 tests). In order to keep the processing time at a minimum, the luminosity data of each image is extracted and computed programmatically. The used program consists of the following steps: (1) segmentation of the images in wear track area and reference area, (2) color transformation of the segmented areas, (3) data extraction and averaging and (4) plotting.

Results and Discussion

Figure 1 plots the absolute luminosity in the wear track (in-track luminosity $L_{in\text{-}track}$) and in the unworn reference area (reference luminosity L_{ref}) versus the sliding distance in the first segment. It shows a spontaneous decline of the in-track luminosity within the very initial stage of the test which corresponds to a sliding distance of about 0.5 km. Thereafter, the in-track luminosity declines continuously until it reaches a steady state after a sliding distance of about 80 km (~ 40 h). In contrast, the reference area which serves as an indicator of the light situation during the whole test, stays on a consistent level throughout the whole test.

Figure 2 plots the relative luminosity ($\Delta L_{rel} = L_{in\text{-}track} / L_{ref} - 1$)·100 % and ring temperature versus the total sliding distance. It shows the ring temperature alternating from 40 to 65 °C in each segment. The results demonstrate that the transfer film formation of PPS/GR30, although it starts with a steep initial drop, still needs over 40 h to reach steady state. It also shows that the luminosity in the first segment becomes steady after the luminosity drops to 65 %. Furthermore, the in-track luminosity shows a cyclically reversible rise to 65 % at 40 °C and a decline to 45 % at 65 °C.

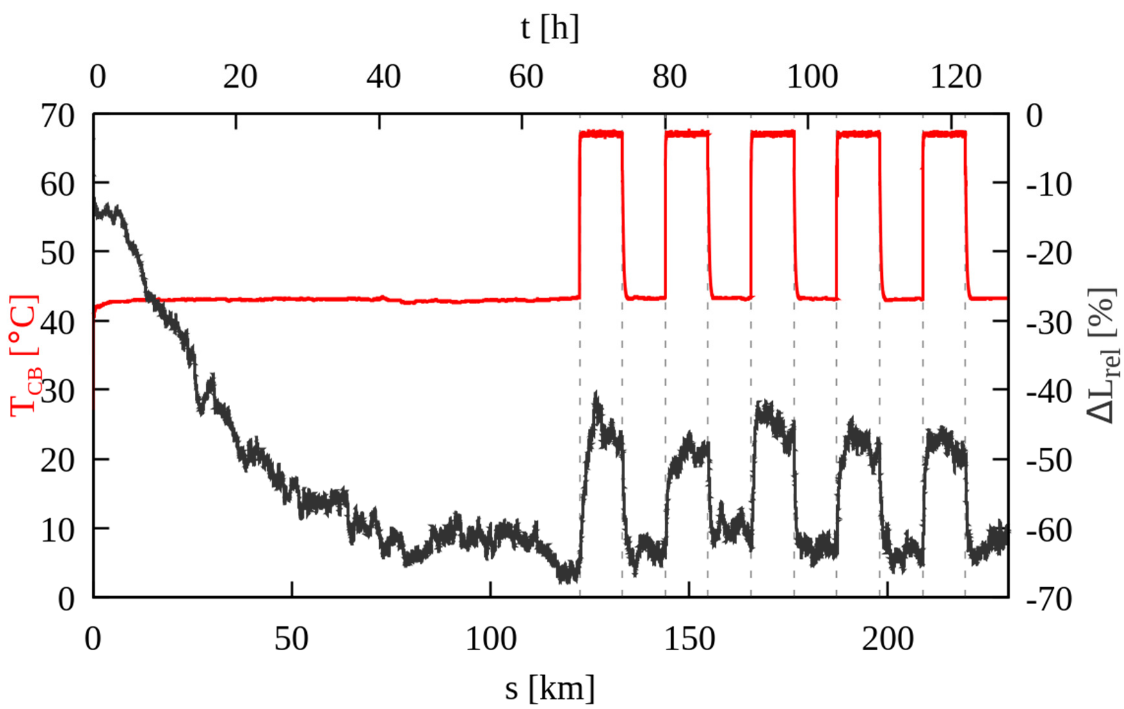

Figure 2: Relative in-track luminosity and steel ring temperature during the whole test

Figure 3 plots the ΔL_{rel} against its average deviation L_a of various PPS compounds filled with graphite (GR), polytetrafluoroethylene (TF) and carbon fibers (CF) (filler content in weight percent) sliding against 100Cr6 bearing steel. The wear tests were conducted at 2 MPa, 0.5 m/s and 20 h. The result exhibit that carbon fibers cause instabilities whereas neat PPS, PPS/TF20 and PPS/GR30 form a more stable transfer film. Particularly RGC39A as filler forms a very prominent transfer film compared to the others. It also demonstrates that RGC39A can reduce ΔL_{rel} instabilities in combined filler compounds, e.g. PPS/CF20/GR15.

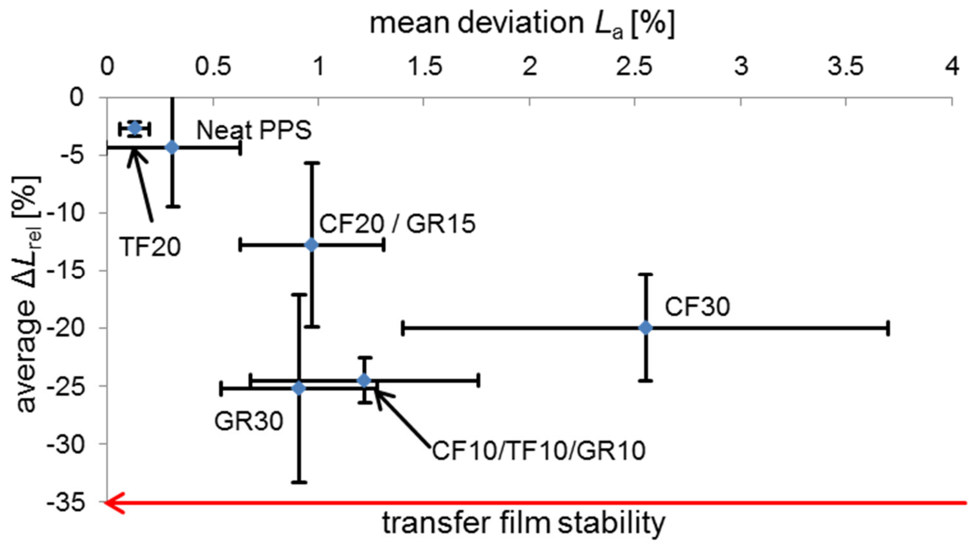

Figure 3: Average relative in-track luminosity ΔL_{rel} vs average deviation L_a of various PPS

Summary and Next Steps

The relative in-track luminosity is a new and reliable quantitative indicator for the formation (and degradation) of a transfer film. Using this indicator, it was demonstrated that the transfer film of PPS/GR30 sliding against 100Cr6 could be tracked with high temporal resolution and that it could be reversibly degraded (partially) and re-formed (to its original extent) by alternating the steel ring temperature to 65 °C and back to 40 °C. Furthermore, it was shown that the stability of formed transfer films correlated with material composition and how certain fillers reduce film formation (CF) whereas other increases the stability (GR, TF).

Based on this primary data ΔL_{rel}, further analysis methods, e.g. statistical methods, are now approachable including kinetic analysis.

Prospective new developments enabled by this technique include new polymeric composites that exhibit rapidly and reproducibly formed transfer films which are thermally and mechanically very stable and efficient in reducing friction and wear at the same time.

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