

# Influence of Humidity and Substrate Roughness on Graphite Lubrication – WTC 2021, Lyon

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In this study, the fundamental wear mechanisms of graphite and influence of humidity were investigated in sliding friction under high mechanical load. By increasing the substrate roughness, a drastic improvement of the tribological behavior could be achieved due to the formation of a thin carbon layer in the tribocontact. The layer has a turbostratic structure with a decreasing degree of graphitization towards the sliding interface, which contradicts the so-called deck-of-cards-model.

Humidity values between 0 – 45% rH were tested and an ideal humidity of 24% rH was found. Experiments in high humidity yielded high friction and wear due to capillary forces.

**Keywords:** graphite, solid lubricants, wear mechanism, humidity

## 1. Introduction

Solid lubricants are used in applications where conventional liquid lubricants reach their limits. One of the well-known solid lubricants is graphite, showing distinct lubrication properties in normal atmosphere but severe wear and friction in vacuum [1]. The most common explanation for the good lubrication properties of graphite is the deck-of-cards-model postulated by Bragg *et al.* [2]. Up to this day, this model is highly debated. Additionally, the reason for the humidity dependence and the underlying lubrication mechanisms are still not completely understood. Our research aims to shine light onto the mechanisms, properties, and limits of graphite lubrication under high mechanical load (> 1 GPa) as well as the influence of humidity on friction and wear.

## 2. Methods

Friction and wear experiments were conducted using graphite-coated iron samples in a microtribometer under reciprocating linear sliding. The influence of the roughness of the substrate and humidity were investigated in detail. The humidity was varied from nearly 0% rH (pressurized air) to 45% rH. After the experiments, the amount of wear and the microstructure were analyzed by confocal microscopy, SEM, FIB, and TEM analyses.

## 3. Results and Discussion

When increasing the roughness of the iron substrate from a mirror polish to a roughness of  $S_A = (81 \pm 4)$  nm, an increased lifetime combined with a lower coefficient of friction ( $\mu = 0.11$ ) as well as a reduced wear coefficient of the counter body was observed. The increased substrate roughness lead to the formation of a 30-150 nm thin carbon layer visible by SEM and TEM analysis, as the graphite remained in the valleys between the substrate's asperities. This thin layer was sufficient to

prolong the lifetime of the two bodies in contact up to seven times due to a longer separation. TEM analyses of the tribolayer revealed a turbostratic structure with parallel graphene layers only visible adjacent to the iron interface (see Figure 1, left side). The degree of graphitization decreased when analyzing multiple points from the iron substrate towards the sliding interface. This contradicts the popular deck-of-cards-model, according to which parallel graphene layers should be observed especially at the sliding interface.

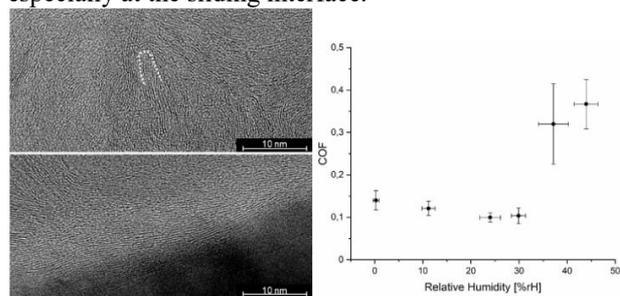


Figure 1: Left side: TEM analysis of the carbon layer in the bulk (upper picture) and at the iron interface (lower picture). Right side: Coefficient of friction vs. the relative humidity in the microtribometer.

When examining the influence of humidity on friction and wear, a minimum was found at 24% rH (see Figure 1, right side). For lower and higher humidity values both friction and wear coefficients were increased. At high humidity values capillary necks are likely to form between the asperities of the two surfaces, thus increasing the local pressure which leads to the observed increased friction and wear.

## 4. References

- [1] Savage, R. H., Graphite Lubrication, *Journal of Applied Physics* 19 (1948) 1–10.
- [2] Bragg, W. H. et al., An introduction to crystal analysis, *Journal of the Society of Chemical Industry* 47 (1928) 1162–1163.