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ANALYSIS OF TRANSFER MECHANISMS OF SOLID-LUBRICATED ROLLING BEARINGS

TRACK OR CATEGORY

4D Materials Tribology II – Solid Lubricants, Coatings and 2D Materials

AUTHORS AND INSTITUTIONS

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INTRODUCTION

Solid lubricated rolling bearings are used in many applications where conventional lubricants cannot be deployed. Those can be high temperature conditions like in steel production factories, ultra-low temperature applications like in cryogenic technology, any vacuum application like x-ray tubes, radiant environments as in nuclear power plants or applications where all of these conditions overlap as in space [1,2]. Even though there are often no alternatives to solid lubricants, market acceptance to solid lubricants is low due to insufficient knowledge about the properties and service life of solid lubricated rolling bearings [2].

SOLID LUBRICATION IN ROLLING BEARINGS

Coatings on the bearings raceways or the rolling elements are implement for separation of the counter bodies in solid lubricated rolling bearings. For applications in vacuum molybdenum disulfide (MoS_2) is one of the most common solid lubricants, but others are also implemented such as silver for example. Wear of the lubricating coatings occurs due to frictional energy transformation in the contacts. In the past, a model for service life calculation was developed by different investigations at the University of Darmstadt, which are cumulated in [2]. The model is based on the assumption that wear is proportional to frictional energy in the raceway contacts. Different researchers [3–5] proved that the service life of solid lubricated rolling bearings can be extended in a significant manner by using the bearings cage as a lubricant deposit. It is expected, that solid lubricant, implemented in the cage, is transferred onto the bearings raceways, whether directly or by the rolling elements as a transportation mean. So far this effect is not implemented in a service life calculation model, as it is not fully understood how the transfer of the solid lubricant from the cage to the raceways occurs [6].

ANALYSIS OF SOLID LUBRICANT TRANSFER IN ROLLING BEARINGS

The analysis of the solid lubricant transfer is the objective of ongoing research at the University of Kaiserslautern. Understanding the transfer will enable a service life calculation that incorporates the availability of solid lubricant as a determining factor of service life in solid lubricated rolling bearings. The transfer process is separated into three steps: release of solid lubricating material from the cage, transport to the raceways and deposition on the raceways. Fig. 1 shows the assembly of the investigated solid lubricated bearings and gives an overview of the material transfer process within the bearing. To distinguish transferred material of the cage from initial lubrication material of the raceway in the analysis, two different lubricants were chosen. The raceways are coated with a 300 nm thick MoS_2 PVD-coating and the cage pockets consist of a polyamide imide (PAI) as the matrix material containing 15 wt.-% of tungsten disulfide (WS_2) particles as solid lubricant. The material was chosen because of its high thermal and mechanical strength and was manufactured by extrusion and injection molding followed by a thermal treatment. After mechanical shaping a second thermal treatment was conducted to reaching ideal mechanical properties of the matrix material [7].

The material transfer is analyzed after the tests using extensive surface analyzing techniques. Scanning electron microscopy (SEM) gives a first idea of the particle allocation on the surface and in combination with focused ion beam (FIB) it enables measuring the thickness of the coatings and transfer films. For higher resolution transmission electron microscopy (TEM) is used. With energy dispersive X-ray spectroscopy (EDX), auger electron spectroscopy (AES) and X-ray photoelectron spectroscopy (XPS) the chemical surface compositions can be determined.

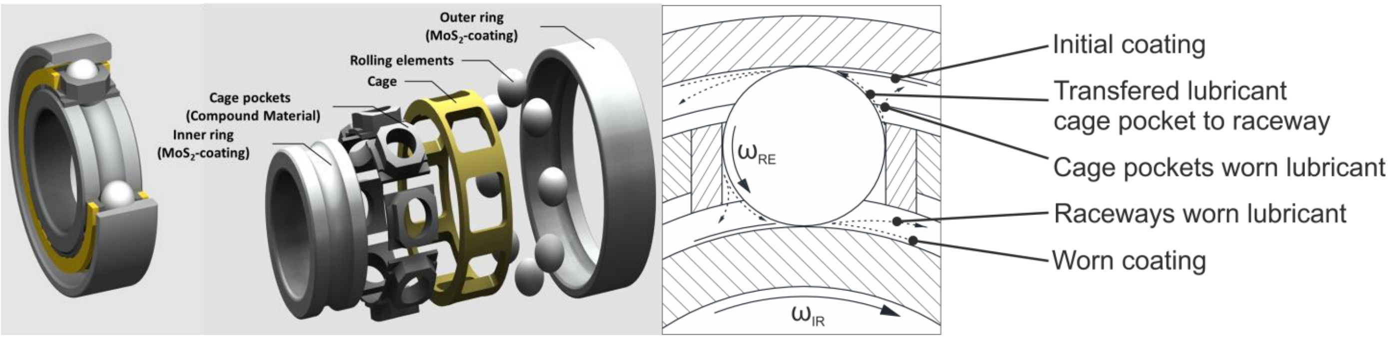


Fig. 1: Left: Assembly of the investigated solid lubricated rolling bearings. Right: Transfer of solid lubricant within rolling bearings

Additional to full bearing tests a block-on-ring tribometer is used for analyzing the release of solid lubricant from the cage material and the deposition on the rolling elements. It simulates the sliding contact between the cage pockets and the rolling elements. For the ring a bearings inner ring is used and a block from the cage material is pressed on its raceway while the ring rotates on its own axis. Results of the tribometer tests are the coefficient of friction μ, the specific wear rate W_S of the material and the material transfer through surface analysis.

The focus of the research is the transfer analysis in fully equipped bearings. Therefore, a four-bearing-test-bench is used for testing four bearings with both radial and axial load under vacuum (< 10^{-4} mbar) conditions. All parts of the bearings are subjected to gravimetric analysis before and after the test for wear calculation. Furthermore, the bearing rings and the rolling elements are subject to the surface analysis to get information about mass distribution of the solid lubricants on the surfaces. The tests operate for different durations to gain knowledge on the transfer process as a function of time or rather frictional energy.

BLOCK-ON-RING TRIBOMETRY RESULTS

Tests on the block-on-ring tribometer ran 20 h (sliding distance of 72 km) if the block did not wear to a critical limit before. In Fig 2. the coefficient of friction (μ) as well as the specific wear rate (W_S) are given for load conditions of p = 1 MPa and v_{rel} = 1 m/s. Results for two different conditions, vacuum and atmosphere, and two different block materials are shown. All blocks are made of PAI with two times containing 15 wt.-% of WS_2. For both mixtures, μ and W_S decrease in a significant manner when going from ambient to vacuum. μ was measured at a steady state phase in the last half of the test and reaches values around 0.5 for ambient and values around 0.1 in vacuum. The specific wear rate acts analog to the coefficient of friction. In air it reaches values between (2…3) $\cdot 10^{-5}$ mm³/Nm while in vacuum values decrease down to $1.5 \cdot 10^{-6}$ mm³/Nm. Comparing the material tested in vacuum with and without tungsten disulfide, it can be seen that the content of 15 wt.-% has a small impact on μ but significantly decreases W_S.

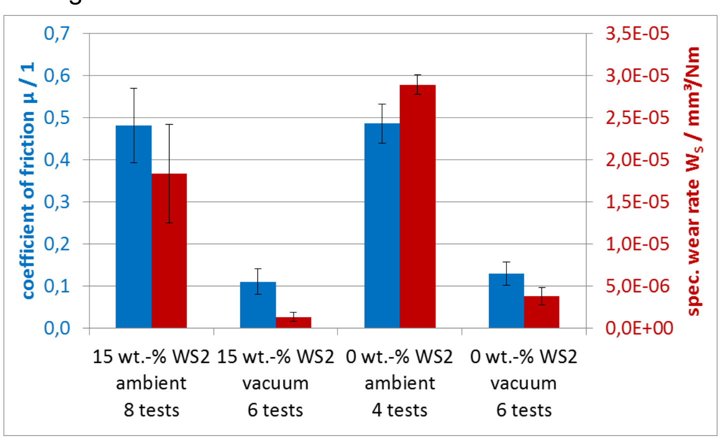


Fig. 2: Coefficient of friction and specific wear rate for block-on-ring tests in ambient and vacuum conditions at load of 1 MPa and speed of 1 m/s

Analyzing the ring's stressed surface after the tests shows the chemical surface compositions, see Fig. 3. The left hand side shows back-scattered-electron (BSE) images. Rings tested in ambient conditions show more of the dark appearing areas, which consist mostly of carbon as more detailed analysis can resolve [8]. With higher resolution those areas can also be found on rings that were tested in vacuum. Focusing on the chemical compositions that is given on the right hand side of Fig. 3, it can be seen that a thicker film is formed on the rings surface at ambient conditions as the concentration of iron (Fe) decreases. In addition, the carbon content is higher, proving that more

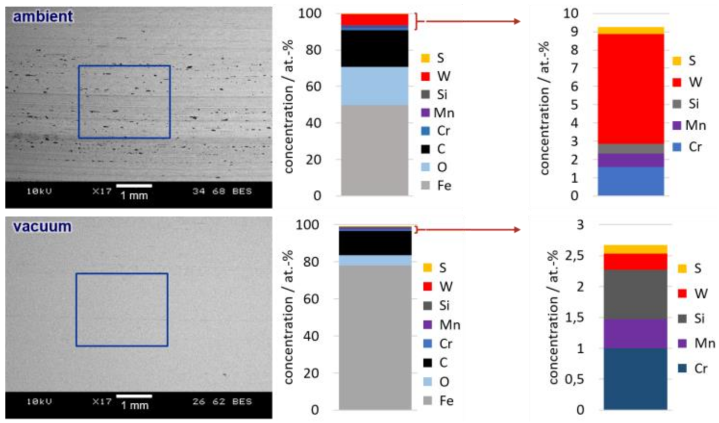
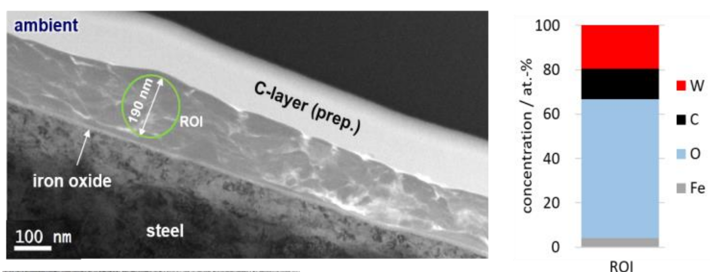


Fig. 3: Back-scattered electron microscopy (BSE) Images and EDX-analysis after block-on-ring test at ambient (top)and vacuum (bottom) conditions

particles of the PAI matrix were transferred onto the rings surface.

Even though on both rings tungsten is found, the tungsten-sulfur-ratio of tungsten disulfide (1:2, WS_2) cannot be found. For ambient conditions, it could be proven that most of the tungsten is bonded in tungsten oxide, not in tungsten disulfide. Fig 4 shows an energy filtered transmission electron microscopy (EFTEM) image of the tribological stressed surface after the block-on-ring test. It can be seen that a closed transfer film has formed on the substrate material with a thickness of around 200 nm. The carbon layer above is build up for the FIB cut preparation. Analyzing the chemical composition of the film using EDX shows that the film consist of around 20 % tungsten, 15 % carbon and 60 % oxygen which confirms that the film consists obviously of tungsten-oxide (WO_3). Hence, material is not only transferred but also transformed during sliding contact, what has to be included in consideration of transfer processes. The TEM investigations of the similar sample tribologically stressed in vacuum show no tungsten oxide layer. Moreover, the high resolution ETFEM reveals a presence of the fragments of WS_2 with the basal planes nearly parallel to the steel surface in vicinity of the iron oxide layer covering steel surface (Fig. 4, bottom). The last observations can perhaps serve as an explanation of the smaller wear found in the tribometry tests in vacuum (compare the 2nd and 4th group results in Fig. 2).



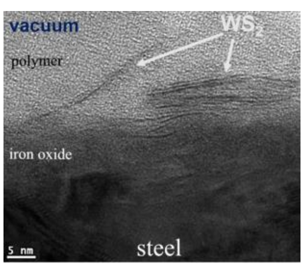


Fig. 4: Energy filtered transmission electron microscopy (EFTEM) images and EDX-analysis after block-on-ring test at ambient (top) and vacuum (bottom) conditions

OUTLOOK

First four bearing tests were conducted and more will follow. Surface analysis of the four bearing tests are subject to further research.

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