Investigation of wear in an oxygen-free atmosphere

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- ☑ Understanding of general tribological behaviour in an oxygen-free atmosphere
- ☑ Investigation of the changed diffusion and adhesion effects
- ☑ Identification of possible transfer films at the active sites
- ☑ Sustainable tool coatings for the inert atmosphere

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IMPT | How does it affect friction and wear when production processes run without oxygen? This is what scientists at the Institute of Micro Production Technology (IMPT) are investigating in the Collaborative Research Centre 1368 "Oxygen-free production".

The demands on economical production processes are constantly increasing. Ever more powerful and efficient production methods are the challenges facing production technology. The production processes of the metalworking industry are usually carried out in an oxygen-rich atmosphere. It has been observed that wear, as a surface phenomenon, is strongly influenced by surface films. The oxygen in the environment causes oxide layers to form on metal surfaces. These increase, for example, the tool wear, for example during machining and forming. The surrounding atmosphere therefore plays a very important role in production processes.

Scientists at the IMPT are investigating the effects of an oxygen-free atmosphere on tribological systems in the Collaborative Research Centre 1368 "Oxygen-free production". They identify and quantify fundamental correlations of wear processes in silane-doped atmospheres, investigate diffusion and adhesion effects and investigate possible novel alloy formations at the interfaces. The aim of the researchers is to use the findings as a basis for the later development of tool coatings in an inert atmosphere.

Effect of the absence of oxygen

Oxygen-free conditions place special demands on tribological systems. Normally, i.e. under atmospheric conditions, the active surfaces of tribologically stressed components have the possibility of forming friction and wear-reducing cover layers through chemical reactions with the gaseous ambient medium. However, this is not possible in an oxygen-free environment.

In the Collaborative Research Centre, the researchers use a silane-doped atmosphere. Through the reaction of the silane with the residual oxygen contained in the inert gas, oxygen partial pressures of less than 10^{-23} bar are achieved at ambient pressure (XHV-adequate atmosphere).

Due to the omission of the cover layers, adhesion mechanisms in the contact areas are increased. These can lead to malfunctions and failure of tribological systems. However, the increased friction coefficients in XHV-adequate atmospheres do not necessarily require a higher wear contribution. Due to the omission of oxide layers, which are often characterized by a lower shear strength, the wear volume is often reduced in an oxygen-free atmosphere.

Atmosphere influences friction coefficients

In order to investigate the influence of the ambient atmosphere on the tribological properties, scientists at the IMPT conducted ball-on-disc studies in normal ambient air, in an argon atmosphere and in a silane-doped atmosphere. For their experiments, the scientists used a universal tribometer (UMT) from Bruker Corporation. The tribometer with a high-temperature chamber allows a maximum temperature of 1000 °C, a maximum force of 10 N and a maximum speed of 500 rpm. In previous experiments, the scientists have preferred oxygen-affine material combinations such as titanium (Ti-6Al-4V) with tungsten carbide and aluminum with aluminum.

The first investigations were carried out with the material pairing tungsten carbide (ball) and Ti-6Al-4V (disc). The tungsten carbide ball with a diameter of 2 mm was pressed onto the titanium surface with an increasing force of 2 N to 7 N or a surface pressure up to about 2.41 GPA. The tests were carried out in different atmospheres and in a temperature range from room temperature to 1000 °C.

It could be shown that the XHV-adequate atmosphere has a considerable influence on the coefficient of friction (CoF). The evaluations showed a significant increase in the coefficient of friction between room temperature and 400 °C. The reason for this is the increased tendency of both friction partners to adhere in the absence of oxygen and the associated suppression of oxide layer formation. From 400 °C on, however, there is a reduction of the CoF, which can be explained by the formation of a tribologically relevant layer in the reactive silane-doped atmosphere. A comparison with the samples in normal atmosphere shows that this layer shows a favorable tribological behavior even above 800 °C.

Formation of novel alloys

New types of alloys are formed in an oxygen-free environment – the scientists were able to show this using scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX). In an XHV-adequate atmosphere, a layer of titanium, oxygen, silicon and aluminum approximately 1 to 2 ?m thick was formed. This layer showed a modulus of elasticity of about 250 GPa and a hardness of about 10 GPa. The elemental distribution at the point of action on the carbide ball showed by EDX measurement that titanium-containing adhesions occurred in the area of high surface pressure. In contrast, silicon-containing adhesions occurred in the outer areas with lower surface pressure.

The investigations on the material pairing aluminum (disc) and aluminum (ball) showed similar results in the same test setup at maximum temperatures up to 500 °C. The coefficient of friction was significantly higher compared to the normal atmosphere, while an increase in the CoF was clearly visible in normal atmosphere as well due to the increase in temperature. Due to the purity of the materials, the scientists were able to detect the beginning of a weld at 400 °C and above in an XHV-adequate atmosphere. This adhesive behavior could also be illustrated by means of SEM images of the sphere. However, the measured wear volume in XHV-adequate atmosphere was considerably lower than in normal atmosphere due to the suppression of chemical wear.

Objective: Sustainable tool coating

The XHV-adequate atmosphere offers innovation potential - this has been shown by the investigations at IMPT. By overcoming existing process limits or using novel tool-material systems, production processes can be realized that were previously not possible.

Based on the knowledge gained about the effects of the silane-doped atmosphere on tribological systems, the IMPT will generate a wear model that takes into account all basic forms of adhesive wear and allows a prognosis of important wear characteristics.

The generated knowledge about the micro- and nanoscopic interactions in the contact area and the resulting coating behavior under XHV-adequate atmosphere will be used in the further course of the Collaborative Research Center to establish novel coatings of materials such as silicon carbide, silicon nitride and diamond-like carbon (DLC) at the IMPT. These materials tend to have a high oxidative wear rate, but have advantageous mechanical properties. In close cooperation with the other subprojects of the Collaborative Research Center 1368, processes and effective zones in an oxygen-free atmosphere are thus being researched in order to develop sustainable production techniques and manufacturing processes.

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