UNIVERSITY OF LEOBEN

Olympus LEXT benefits the world of tribo-fatigue

Damage limitation

Research at the Department of Product Engineering, Institute of Mechanical Engineering, University of Leoben, Austria, is centred on method development in the fields of machine elements, tribology, fatigue analysis and selected areas of vehicle construction. Tribology is the science of surfaces in contact under relative motion, and deals with all phenomena involving wear, friction and lubrication. This ranges from technical systems, such as gearboxes and engines, to artificial heart valves and hip joints. However, the main focus of research at the Institute concerns tribology and fatigue, known as tribo-fatigue. The Olympus LEXT has been a key instrument in this field, allowing them to specifically examine both the tribological behaviour and wear-fatigue fracture surface characterisation of various tribomaterials, the development of tribological test methods, as well as the optimisation of sliding bearing materials.

The science of tribology

Tribology is a broad discipline, which has only begun to develop during the last forty years. Defined as the science and technology of interacting surfaces in relative motion, tribological research involves the study and application of friction, lubrication and wear on tribomaterials. Tribology is commonly applied in bearing design, but also extends into almost all other aspects of modern technology. Any product where one material slides or rubs over another is affected by complex tribological interactions.
Tribology also plays an important role in manufacturing and in metal-forming operations. Since friction increases tool wear, as well as the power required to work a piece. This in turn, results in increased costs due to more frequent tool replacement, loss of tolerance as tool dimensions shift and greater forces are required to shape a piece. A layer of lubricant which reduces surface contact virtually eliminates tool wear and decreases needed power significantly.

**Tribo-fatigue**

Tribo-fatigue has been determined as the new scientific trend in tribology. The tribo-loaded part of any machine is called the “active system”, which can be defined as any mechanical system that operates in the conditions of the contact interaction between elements (sliding, rolling and slippage) and simultaneously transmits cyclic workload. Thus, tribo-fatigue describes the mechanics and the processes of emerging and developing wear-fatigue damage and fracture of active systems of machines and equipment.

The mechanics of fatigue fracture has emerged among general problems of dynamics, strength and stability. Tribo-fatigue has become essential in solving complex problems related to the reliability of the key systems of machines and equipment – active systems. The aim of tribo-fatigue research is to create reliable mechanical systems, and this opens up new perspectives for increasing the durability of machines according to the most important criteria of their serviceability.

**Tribomaterials**

Tribomaterials include all materials used in applications where friction and wear is important, and must be extremely hard to endure the contact against other hard, sharp or rough materials (diamond and ceramics), as well as hard and plastically deformable materials (steel or elastic-like-
rubber) to be able to adjust its shape to the counter surface. Tribomaterials, therefore, must fulfill a combination of functions, including: not to stress their environment, not to cause allergic reactions, not release particles and not cause noise for example. Furthermore, the effect of severe external conditions, such as extreme pressures, high temperatures and corrosive atmospheres, also need to be considered. Thus, the set of demands is very complex and is often fulfilled by composites or surface engineered materials combining the required properties.

**Surface analysis of tribomaterials**

Fatigue and wear are the most dangerous damaging phenomena of modern machines, causing approximately 90% of failures. Any practical analysis of the processes of mechanical fatigue, as well as friction and wear are based on the key idea that the characteristics of these processes are affected (usually through damage) by numerous factors. These can be classified into four groups: factors of design, metallurgy, production process and operation.

The traditional assessment of reliability of a certain mechanical system using individual criteria - either resistance to fatigue or resistance to wear - implies that the relationship between its elements is either weak (tribology: only the friction pair is studied), or totally absent (the mechanics of fatigue strength: only an individual structural element is studied). Advanced testing methods have now become more and more capable of characterising these tribological events. However, it is not always possible to investigate events taking place in tribomaterials using component tests. Therefore, developing tribological test methods at the model scale enables the events occurring in sliding materials during operation and subsequent breakdown to be demonstrated, such as detailed damage measurement and wear-fatigue tests that enable engineers to design more durable and reliable systems.
METHODS

The design of tribomaterials is a compromise of differing demands, and is always of multi-phase composition either by nature or by mutations due to tribological loading. Tribomaterials for sliding applications are mostly material composites, and can be classified on the basis of their principle set-up. Researchers Dr István Gódor, Dr Florian Grün and Dr Michael Stoschka at the CD-laboratory for Fatigue Analysis, Institute of Mechanical Engineering, Leoben, are interested in two major material groups. One is based on a hard, load bearing matrix, whereby the tribological properties are improved by adding softer inclusions that possess lower melting points, such as the alloy for an anti-friction element CuPb22Sn2. The other major material group comes with a soft matrix, which already posses good sliding properties and is reinforced with harder particles, such as Polytetrafluoroethylene (PTFE) and bronze (Bz).

In this study, the development of model scale tribological test methods using the model ring-on-disc is presented. The methods enable the demonstration of processes that occur in sliding materials during operation and subsequent breakdown. Currently, existing test methods are not able to visualise these complex processes to the same extent. Therefore, to characterise and visualise the behaviour of different materials and their properties, Gódor and his colleagues designed adapted test programmes. They benchmarked the test methods on selected metal-based and plastic tribomaterials, CuPb22Sn2 and PTFE+Bz, under lubricated and non-lubricated conditions. Furthermore, they conducted an extensive damage analysis of the surface and surface layers. The classification of the damage patterns and the tribometric results can then form the basis for the development of models that are capable of representing the most important states during operation.
The LEXT level

To deduce models that describe the material behaviour, the test methods have to be combined with accompanying damage analysis studies. A confocal laser scanning microscope (cLSM), the Olympus LEXT OLS3100 (figure 1), was used along with a scanning electron microscope (SEM) to follow damage analysis and for the development of tribological models. A SEM enables researchers to get an extremely close up view of the subject, and in combination with the LEXT has helped with the assessment of finished technical surfaces and chemical surface layer recognition. The LEXT provides illustrations of surfaces in 3D, as well as enabling the analysis of fractured surfaces, evaluation of roughness and the measurement of wear, with reproducibility within 0.02 μm. Figure 2 illustrates how the LEXT is used as a non-destructive tool to measure the surface topology of a notched specimen, as it is necessary to know the “real” diameter and roughness before testing.

Technical surface analysis

Finished technical surfaces possess individual properties, which depend on the used surface finish technique and its parameters. With cLSM a topographic image is generated, figure 3a shows a typical topography of a machined surface. This is characteristic of a turning process and can be described by surface phenomena. Three major grooves together with smaller scores are visible in the cut-out of a round specimen. Besides the topography, the microstructure of the boundary level influences the component properties, which can be seen in figure 3b. This SEM image indicates that high plastic deformation was generated during machining. When cLSM analysis is combined with SEM data, a whole new level of results can be generated.
**Tribological overload analysis**

The surface integrity, involving both topography and microstructure, can be further modified if the surface is subjected to tribological loading. The stability limit of a tribosystem and its dry running properties can be investigated using step tests. By measuring COF levels, different states that are typical for sliding materials incorporated with soft phases can be determined. After a running-in phase, in which, predominantly, the surface topography changes, the soft phases contribute to the good dry running properties of the system. However, if stability is lost due to tribological overload, the soft phase, which is lead (Pb) in the case of CuPb22Sn2, melts as a result of the immediately rising temperature. This process consumes energy and the lead may act as a liquid lubricant, causing the system to fail due to seizure. This load limit is called the seizure load limit.

Typical surfaces after seizure are presented in figure 4a and 4b. In 4a, the soft phase Pb has left the microstructure of CuPb22Sn2 and acted as a liquid lubricant. Figure 4b, shows a torn up surface of a PTFE+Bz compound. These changes in the surface layer and microstructure are called tribomutations.

**RESULTS**

As a result of studies using cLSM in combination with SEM, Gó dor and Grün have deduced models of the material behaviour for CuPb22Sn2. The two phase material CuPb22Sn2 comes with a copper (Cu) matrix, which is hardened with tin (Sn), and the melting point of the soft phase lead (Pb) is 327°C. CuPb22Sn2 is often used as a lining material for journal bearings, where it is typically cast on a steel back and possesses a dendritic microstructure, as shown in figure 5a.

If loaded tribologically, the microstructure is deformed (figure 5a and 5b),
however, at this stage the bearing component is still fully functional. An increase of the tribological load leads to further mixing processes, and as shown in the SEM image in figure 5b, a few cracks have appeared in the microstructure. The zones underneath the surface, which appear dark in the LEXT image (figure 5a), are predominantly deformed Pb phases.

**DISCUSSION**

The Olympus LEXT OLS3100 confocal laser scanning microscope has made an important impact on Dr István Gódar, Dr Florian Grün and Dr Michael Stoschka’s work in examining both the tribological behaviour and fracture surfaces of different tribomaterials. Furthermore, this technique has enabled the events that are taking place in sliding materials to be described. This is due to the fact that cLSM instruments, such as the LEXT, are very versatile providing advanced surface profiling. Additionally, damage analysis assists in specifying the events taking place in tribomaterials. By slowing down the breakdown process, enough time can be given for damage analysis of the interacting boundary layers for the designed materials PTFE+Bz and CuPb22Sn2 models. Moreover, these models are of sufficient quality to assist in further optimising of the tribo materials.

**GLOSSARY**

*Tribology* is the science of surfaces in contact under relative motion.

*Tribo-fatigue* describes the mechanics and the processes of emerging and developing wear-fatigue damage and fracture of active systems of machines and equipment.

*Tribomaterials* include all materials used in applications where friction and wear is important.
**Active system** is the tribo-loaded part of any machine, and is defined as any mechanical system that operates in the conditions of the contact interaction between elements (sliding, rolling and slippage) and simultaneously transmits cyclic workload.

**CONTENTS ABSTRACT**

The main focus of research at the Institute of Mechanical Engineering concerns tribology and fatigue, known as tribo-fatigue. The Olympus LEXT has been a key instrument in this field, allowing them to specifically examine both the tribological behaviour and wear-fatigue fracture surface characterisation of various tribomaterials, the development of tribological test methods. Furthermore, this technique has enabled the events that are taking place in sliding materials to be described. Results demonstrated that damage analysis assists in specifying the events taking place in tribomaterials. By slowing down the breakdown process, enough time can be given for damage analysis of the interacting boundary layers for the designed materials PTFE+Bz and CuPb22Sn2 models. Moreover, these models are of sufficient quality to assist in further optimising of the tribo materials.
FIGURES

Figure 1: The Olympus LEXT OLS3100 confocal laser scanning microscope

Figure 2: The Olympus LEXT OLS3100 confocal laser scanning microscope used as a non-destructive tool to measure the surface topology of a notched specimen before testing
**Figure 3a:** With cLSM a topographic image is generated, and the topography of a machined surface is shown.

**Figure 3b:** Surface layer – conditions of the microstructure of the boundary level influences the component properties.
**Figure 4a**: Surface after seizure – CuPb22Sn2

**Figure 4b**: Damaged surface – PTFE+Bz
Figure 5a: The microstructure of CuPb22Sn2. CuPb22Sn2 is often used as lining material for journal bearings, where it is typically cast on a steel back and possesses a dendritic microstructure.

Figure 5b: An increase of the tribological loading leads to further mixing. This image shows that a few cracks have appeared in the microstructure.
Please contact:

OLYMPUS LIFE SCIENCE EUROPA GMBH
Microscopy
Esther Ahrent
Department Manager Marketing Communication
Tel: +49 40 2 37 73 - 5426
Fax: +49 40 2 37 73 - 4647
E-mail: microscopy@olympus-europa.com
www.microscopy.olympus.eu