STUDY AND CHARACTERISTIC OF ABRASIVE WEAR MECHANISMS

Ingrid KOVAŘÍKOVÁ, Beáta SZEWCZYKOVÁ, Pavel BLAŠKOVITŠ, Erika HODÚLOVÁ, Emil LECHOVIČ

Authors: *Ing. Ingrid Kovaříková, PhD., Ing. Beáta Szewczyková, Prof. Ing. Pavel Blaškoviš, DrSc., Ing. Erika Hodúlová, PhD., Ing. Emil Lechovič*

Workplace: *Institute of Production Technologies, Faculty of Materials Science and Technology, Slovak University of Technology*

Address: *ul. Jána Bottu 23, 917 24 Trnava, Slovak Republic*

E-mail: *ingrid.kovarikova@stuba.sk, beata.szewczykova@stuba.sk, pavel.blaskovits@stuba.sk, erika.hodulova@stuba.sk, emil.lechovic@stuba.sk*

Abstract

The main subjects of this paper are the tribotechnical system and abrasive wear. Regarding the tribotechnical system essential information on structure, real contact geometry, tribological loads, operating and loss variables are provided. Wear by abrasion is form of wear caused by contact between a particle and solid material. Abrasive wear is the loss of material by the passage of hard particles over a surface. Abrasion in particular is rapid and severe forms of wear and can result in significant costs if not adequately controlled. These differences extend to the practical consideration of materials selection for wear resistance due to the different microscopic mechanisms of wear occurring in abrasion. The questions are: where are abrasive wear likely to occur? When do these forms of wear occur and how can they be recognized? What are the differences and similarities between other types of wear?

Key words

tribology, tribotechnical system, wear mechanisms, abrasive wear, wear resistance

Tribology

Tribology is the science and technology of interacting surfaces in relative motion. Tribology includes boundary-layer interactions both between solids and between solids and liquids and/or gases. Tribology encompasses the entire field of friction and wear, including lubrication (fig. 1) [1].

Tribology aims to optimize friction and wear for a particular application case. Apart from fulfilling the required function, this means assuring high efficiency and sufficient reliability at the lowest possible manufacturing, assembly, and maintenance costs.

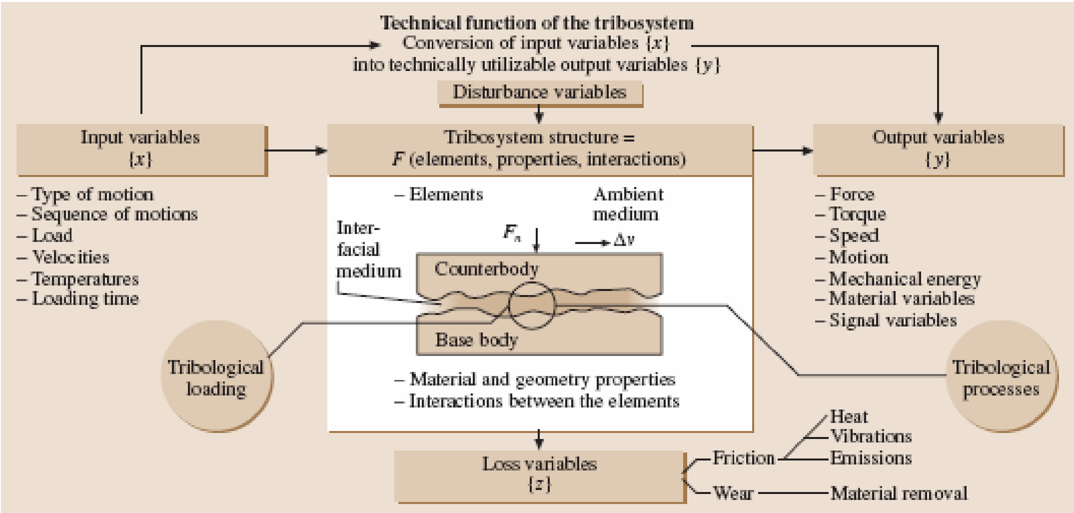


Fig. 1 *Expanded representation of a tribotechnical system (TTS) [2]*

Tribotechnical system

General Description

Friction and wear occur within a tribotechnical system (TTS). To delimit a TTS, a system envelope is appropriately placed around the components and materials directly involved in friction and wear, thus virtually isolating these from the remaining components. The materials and components involved in friction and wear are the elements of the TTS and are characterized by their material and shape properties. A tribotechnical system is described by the function to be fulfilled, the input variables (operating variables), the output variables, the loss variables, and the structure (Fig. 1).

Structure

The elements involved, their properties, and the interactions between the elements describe the structure of a TTS. The basic structure of all TTS consists of four elements: the base body, counterbody, interfacial medium, and ambient medium (Fig. 1). Table 1 displays some TTS with different elements. While the base body and counterbody are found in every TTS, the interfacial medium and, in a vacuum, even the ambient medium can be absent.

EXAMPLES THE TRIBOTECHNICAL SYSTEMS ELEMENTS [2] Table 1

TTS	Base body	Counterbody	Interfacial	Ambient medium	System type
Press and shrink joints	Shaft	Hub	-	Air	Closed
Sliding bearing	Journal	Bearing bush	Oil	Air	Closed
Mechanical face seal	Seal head	Seat	Liquid or gas	Air	Closed
Gear train	Pinion	Wheel	Gear oil	Air	Closed
Wheel/rail	Wheel	Rail	Moisture, dust, grease	Air	Open
Excavator bucket/excavated material	Bucket	Excavated material	-	Air	Open
Turning tool	Cutting edge	Work piece	Cutting lubricant	Air	Open

Tribologically relevant properties of elements of the tribotechnical system (TTS) [1].

1. Base body and counterpart

1.1 *Geometric properties*

• External dimensions

• Shape and position tolerances

• Waviness

• Surface roughness's

1.2 *Material properties*

1.2.1 Bulk material

• Strength

• Hardness (macro, micro, and Martens hardness)

• Structure, texture, microstructure phases

• Modulus of el. Poisson's ratio

• Residual stress

• Chemical composition (distribution, size, number type)

1.2.2 Near-surface zone

• Hardness (macro, micro, and Martens hardness)

• Surface energy

• Metallurgical structures, texture, microstructure

• Chemical composition

• Modulus of el. Poisson's ratio

• Residual stress

• Boundary-layer thickness and structure phases (distribution, size, number type)

1.3 *Physical variables*

• Density
• Heat conductivity
• Coefficient of thermal expansion
• Melting point
• Spec. thermal capacity
• Hygroscopic properties

2. Interfacial medium (lubricant)

• Aggregate state (solid, liquid, gaseous)
• For *solid* interfacial medium

• For *liquid* interfacial medium

– Hardness – Viscosity depending on temperature, pressure, shear rate
– Grain size distribution – Consistency
– Grain shape – Wettability
– Grain quantity, grain number – Lubricant quantity and pressure
– Number of components, mixing ratio – Chemical composition
– Chemical composition – Mixing ratio of components

3. Ambient medium

• Aggregate state (solid, liquid, gaseous)
• Heat conductivity
• Chemical composition
• Moisture
• Ambient pressure

Wear

General

As soon as the base body and counterbody come into contact, i. e., when the lubrication film thickness becomes too small or lubricant is unavailable, wear occurs. Wear is a progressive loss of material from the surface of a solid, brought about by mechanical causes, i. e., by contact and relative motion of a solid, fluid or gaseous counterbody (fig. 1). Signs of wear are small detached wear particles, material removal from one friction body to the other, and material and shape changes of the tribologically loaded material zone of one or both friction partners.

Types and Mechanisms of Wear

Wear processes can be classified into different types according to the type of tribological load and the materials involved, e.g., sliding wear, fretting wear, abrasive wear, and material cavitation. Wear is caused by a number of mechanisms, the following four being especially important:

• Surface fatigue
• Abrasion
• Adhesion
• Tribochemical reaction

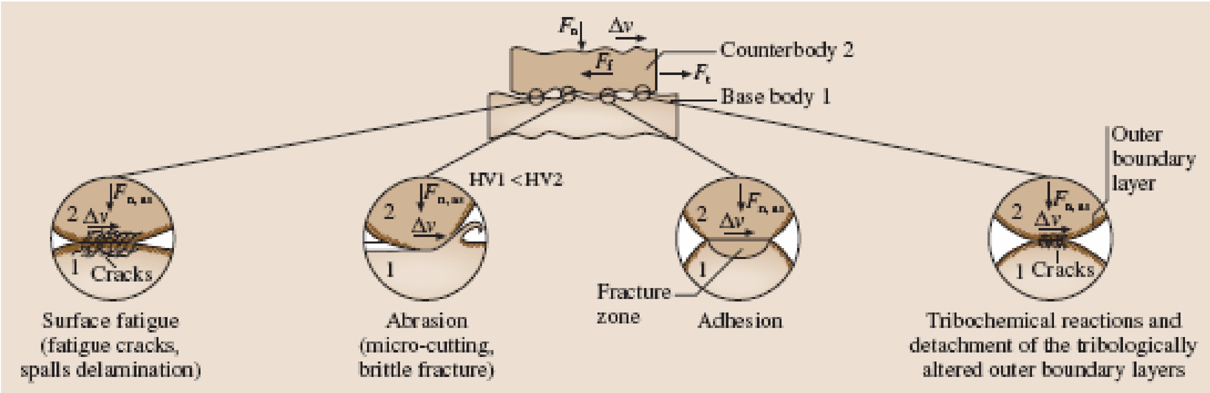


Fig. 2 *Basic wear mechanisms viewed microscopically (Fn normal force on apparent contact surface, Ff friction force between base body and counterbody, Fn, as normal force on asperity contact, Δv relative velocity, HV Vickers hardness) [3]*

Figure 2 presents a chart of the effective wear mechanisms. The wear mechanisms can occur individually, successively or concomitantly. Surface fatigue manifests itself through cracking, crack growth, and detachment of wear particles, brought about by alternating loads in near-surface zones of the base body and counterbody.

In *abrasion* microcuttings, fatigue due to repeated ploughing, and fracture of the base body caused by the counterbody's hard asperities or by hard particles in the interfacial medium lead to wear.

In *adhesion*, after possibly extant protective surface layers have been broken through, atomic bonds (microwelds) form above all on the plastically deformed microcontacts between the base body and counterbody. If the strength of the adhesive bonds is greater than that of the softer friction partner, material eventually detaches from the deformed surface of the softer friction partner and is transferred to the harder one. The transferred material can either remain on the harder friction partner or detach, or even return.

In *tribochemical reactions*, friction-induced activation of loaded near-surface zones causes elements of the base body and/or counterbody to react chemically with elements of the lubricant or ambient medium. Compared with the base body and counterbody, the reaction products exhibit changed properties and, after reaching a certain thickness, can be subject to brittle chipping or even exhibit properties reducing friction and/or wear.

Apart from the types and mechanisms of wear, *wear phenomena* are also extremely interesting for interpreting the result of wear (Table 2). These mean the changes of a body's surface layer resulting from wear and the type and shape of the wear particles accumulating. Light or scanning electron microscope images can present this extremely clearly (1, 4).

TYPICAL WEAR PHENOMENA CAUSED BY THE MAIN WEAR MECHANISMS [1]

Table 2

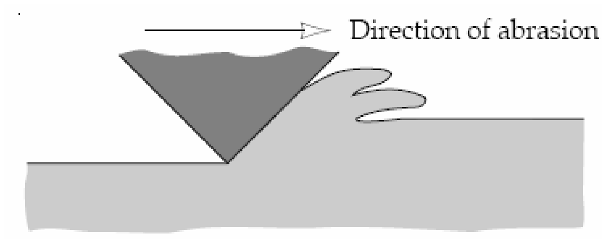
Wear mechanism	Wear phenomenon
Adhesion	Scuffing or galling areas, holes, plastic shearing, material transfer
Abrasion	Scratches, grooves, ripples
Surface fatigue	Cracks, pitting
Tribochemical reaction	Reaction products (layers, particles)

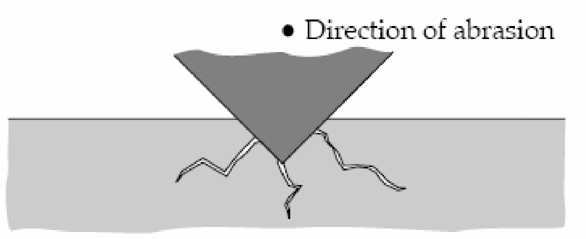
Abrasive Wear

Abrasive wear occurs whenever a solid object is loaded against particles of a material that have equal or greater hardness. A common example of this problem is the wear of shovels on earth-moving machinery. The extent of abrasive wear is far greater than may be realized. Any material, even if the bulk of it is very soft, may cause abrasive wear if hard particles are present. For example, an organic material, such as sugar cane, is associated with abrasive wear of cane cutters and shredders because of the small fraction of silica present in the plant fibers [5]. A major difficulty in the prevention and control of abrasive wear is that the term 'abrasive wear' does not precisely describe the wear mechanisms involved. There are, in fact, almost always several different mechanisms of wear acting in concert, all of which have different characteristics.

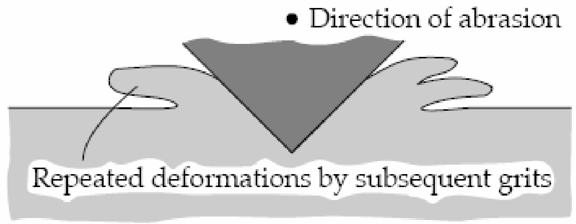
Mechanisms of Abrasive Wear

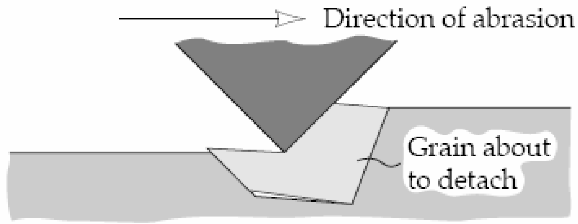
It was originally thought that abrasive wear by grits or hard asperities closely resembled cutting by a series of machine tools or a file. However, microscopic examination has revealed that the cutting process is only approximated by the sharpest of grits and many other more indirect mechanisms are involved. The particles or grits may remove material by microcutting, microfracture, pull-out of individual grains [6] or accelerated fatigue by repeated deformations as illustrated in Figure 3.





a) Cutting b) Fracture





c) Fatigue by repeated ploughing d) Grain pull-out

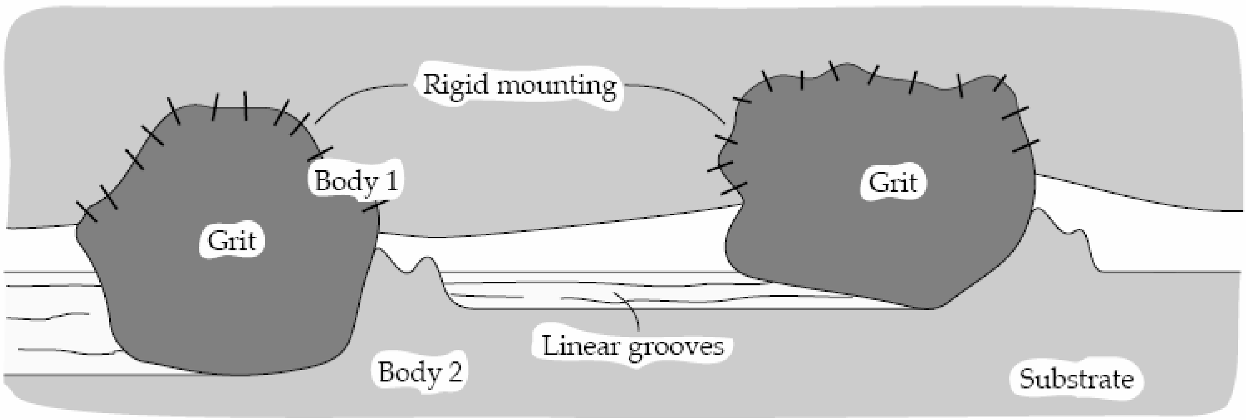
Fig. 3 *Mechanisms of abrasive wear: microcutting, fracture, fatigue and grain pull-out [6]*

The first mechanism illustrated in Figure 3a, cutting, represents the classic model where a sharp grit or hard asperity cuts the softer surface. The material which is cut is removed as wear debris. When the abraded material is brittle, e.g. ceramic, fracture of the worn surface may occur (Figure 3b). In this instance wear debris is the result of crack convergence. When a ductile material is abraded by a blunt grit then cutting is unlikely and the worn surface is repeatedly deformed (Figure 3c). In this case wear debris is the result of metal fatigue. The last mechanism illustrated (Figure 3d) represents grain detachment or grain pull-out. This mechanism applies mainly to ceramics where the boundary between grains is relatively weak. In this mechanism the entire grain is lost as wear debris.

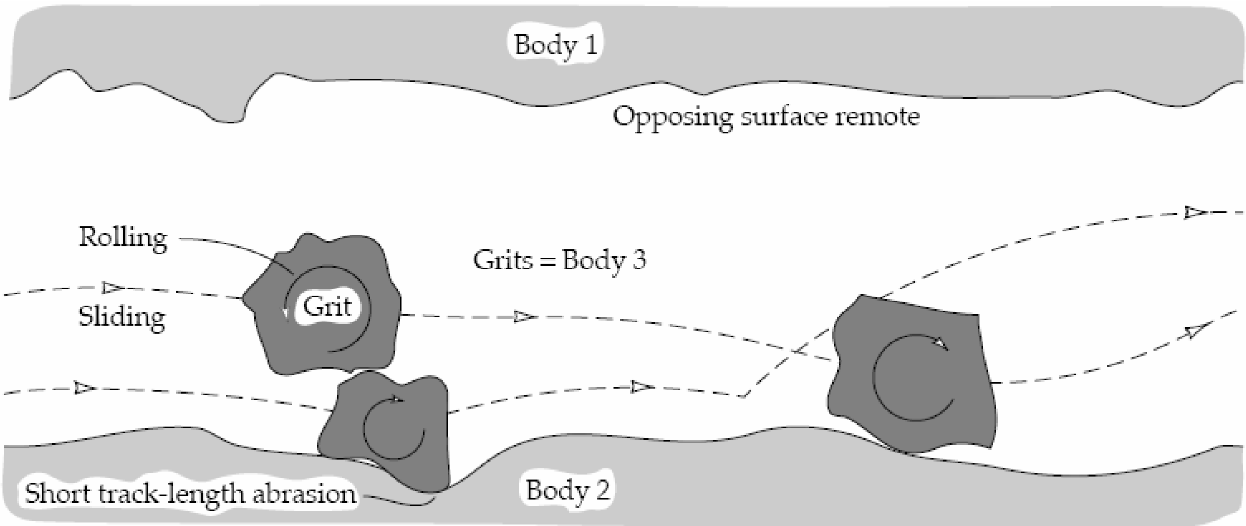
Modes of Abrasive Wear

The way the grits pass over the worn surface determines the nature of abrasive wear. The literature denotes two basic modes of abrasive wear:
· two-body and
· three-body abrasive wear.

Two-body abrasive wear is exemplified by the action of sand paper on a surface. Hard asperities or rigidly held grits pass over the surface like a cutting tool. In three-body abrasive wear the grits are free to roll as well as slide over the surface, since they are not held rigidly. The two and three-body modes of abrasive wear are illustrated schematically in Figure 4.



Two-body mode



Three-body mode

Fig. 4 *Two and three-body modes of abrasive wear [7]*

Until recently these two modes of abrasive wear were thought to be very similar, however, some significant differences between them have been revealed [7]. It was found that three-body abrasive wear is ten times slower than two-body wear since it has to compete with other mechanisms such as adhesive wear [8]. Properties such as hardness of the "backing wheel", which forces the grits onto a particular surface, were found to be important for three-body but not for two-body abrasive wear. Two-body abrasive wear corresponds closely to the 'cutting tool' model of material removal whereas three-body abrasive wear involves slower mechanisms of material removal, though very little is known about the mechanisms involved [9]. It appears that the worn material is not removed by a series of scratches as is the case with two-body abrasive wear. Instead, the worn surface displays a random topography suggesting gradual removal of surface layers by the successive contact of grits [10].

Conclusion

The mechanisms of abrasive wear is extremely interesting for interpreting the wear because abrasive wear is very common type of wear in mining, agriculture, cement industry, civil engineering, metallurgy.

Depends of the mechanisms we can prepare working surfaces with exact chemical composition and heat treatment for example by hard facing technologies.

Acknowledgement

This work was supported by the Slovak research and Development Agency under the contract No **APVV-0057-07, VEGA 1/0381/08, APVT-20-011004.**

References:

[1] Gesellschaft für Tribologie e.V.: *GfT Arbeitsblatt 7: Tribologie - Verschleiß, Reibung, Definitionen, Begriffe, Prüfung* (GfT, Moers 2002), in German

[2] CZICHOS, H., HABIG, K.H. *Tribologie-Handbuch; Reibung und Verschleiß*, 2nd edn. (Vieweg, Wiesbaden 2003), in German

[3] KRAGELSKI, J.W. *Reibung und Verschleiß* (VEB Technik, Berlin 1971), in German

[4] HABIG, K. H. Tribologie. In *Dubbel – Taschenbuch für den Maschinenbau*, 21st edn., ed. by K.-H. Grote, J. Feldhusen (Springer, Berlin, Heidelberg 2004), in German

[5] BUNN, C.W., HOWELLS, E.R. Structures of Molecules and Crystals of Fluorocarbons, *Nature*, Vol. 174, 1954, pp. 549-551.

[6] POOLEY, C.M., TABOR, D. Friction and Molecular Structure: the Behaviour of some Thermoplastics, *Proc. Roy. Soc., London,* Series A, Vol. 329, 1972, pp. 251-274.

[7] BLANCHETT, T.A., KENNEDY, F.E. The Development of Transfer Films in Ultra-High Molecular Weight Polyethylene/Stainless Steel Oscillatory Sliding, *Tribology Transactions,* Vol. 32, 1989, pp. 371-379.

[8] EISS, N.S., WOOD, K.C., HEROLD, J.A., SMYTH, K.A. Model for the Transfer of Polymer to Rough, Hard Surfaces, *Transactions ASME, Journal of Lubrication Technology*, Vol. 101, 1979, pp. 212-219.

[9] WARREN, J. H., EISS, N. S. Depth of Penetration as a Predictor of the Wear of Polymers on Hard, Rough Surfaces, *Transactions ASME, Journal of Lubrication Technology,* Vol. 100, 1978, pp. 92-97.

[10] EISS, N. S., SMYTH, K. A. The Wear of Polymers Sliding on Polymeric Films Deposited on Rough Surfaces, *Transactions ASME, Journal of Lubrication Technology,* Vol. 103, 1981, pp. 266-273.

[11] STACHOWIAK, G. W., BATCHELOR, A. W. Engineering tribology - 3rd ed. p. cm., ISBN 0-7506-7836-4, Printed in the United States of America