FRICTION, WEAR AND LUBRICATION

MEMM 1343

Tribochemical reactions

Tribochemical reactions cause material alterations in the surface of tribo-bodies. In contrast to adhesion , in this case a chemical reaction takes p lace on the surface with the ambient medium and / or the intermediate material , and not with the counterbody material.

This differs from corrosion , in that tribochemical reactions take place only on the contact surface, during simultaneous relative motion. The reaction products of the tribochemical reactions actively influence the course of the wear process.

The frictional processes brought about by the relative motion ma y result in frictional losses , such as frictional heat. At the same time , the naturally occurring reaction layers on the material surfaces are destroyed by mechanical loading , so that high-energy surface regions become exposed. The enhanced capacity of the surfaces to enter into chemical reactions leads to tribochemical reactions , such as tribo-oxidation.

The altered chemical composition of the surface in turn influences its properties in respect of strength and frictional values. The reaction products – both those arisin from the natural reaction layers and those arising from tribochemical reactions – can be very hard and brittle (e.g., metal oxides).

If these break away due to mechanical loading , they contribute additionally to progressive wear (abrasion), thus sustaining the ongoing tribochemical reactions.

A typical example of tribochemical wear is the formation of fretting corrosion which can develop on stainless steels when the protective passive layers are continuously destroyed. In order to prevent tribochemical reactions from occurring, materials should be chosen which are chemically inert relative to the ambient medium and intermediate material.

A suitable additive in the lubricant can prevent tribochemical reactions from occurring, via the formation of a protective layer on the surface of the material.

Surface fatigue

Besides static loading, alternating mechanical loads can also occur in tribological systems, and may be described as a “periodic oscillation” as shown in Figure 1.

Dynamic loading in the surface regions of materials can cause material fatigue in the edge zone, leading ultimately to the formation of cracks and their subsequent spreading.

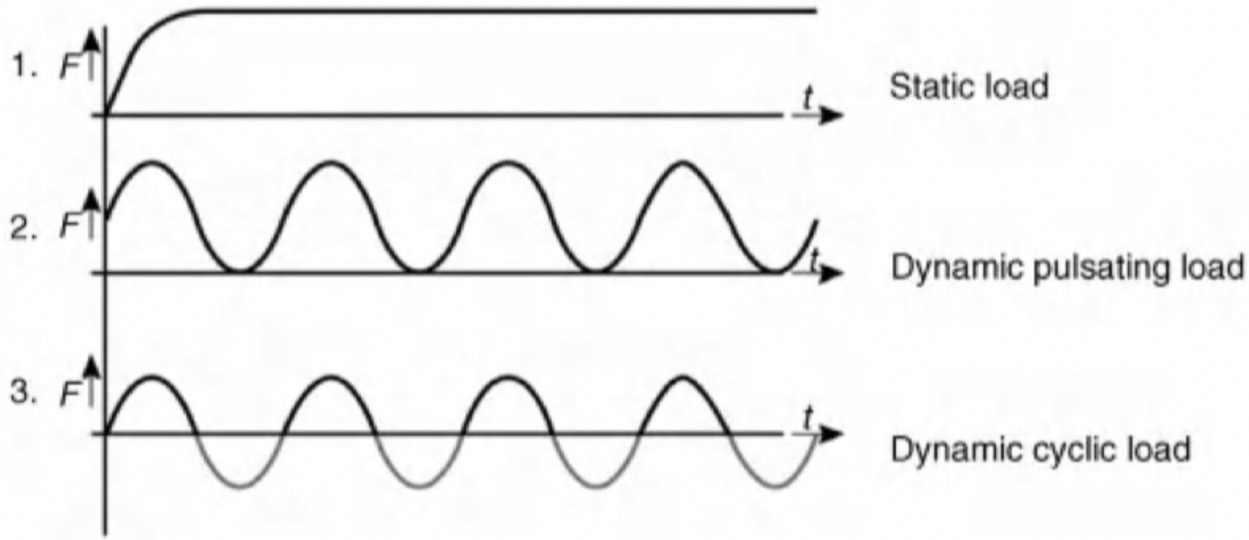


Figure 1: Time behavior of cases of mechanical loading.

Surface fatigue exhibits certain similarities with the volume-based fatigue of massive materials. The difference lies in the smaller penetration depth of the loads acting, which in surface destruction act only in the edge zone of a material.

Material fatigue can also result in fracture for load amplitudes below the static yield strength. Cracks are formed on the surface, especially at faulty positions with stress concentration. These grow further step-wise, and the residual cross-section ultimately fails due to forced rupture.

Likewise, with cyclically loaded sliding contacts, forms of wear phenomena are observed similar to those known from volume-based fatigue fracture in the manner of “lines of oscillation” and “lines of rest”.

Well before the formation of cracks, material fatigue already becomes apparent in the micro-structure. The prerequisite for fatigue is the plastic deformation of the material; when the applied load exceeds the elastic limit, the crystal begins to undergo plastic deformation, which may be attributed to the migration of displacements (linear lattice defects) along the slip planes as shown in Figure 2.

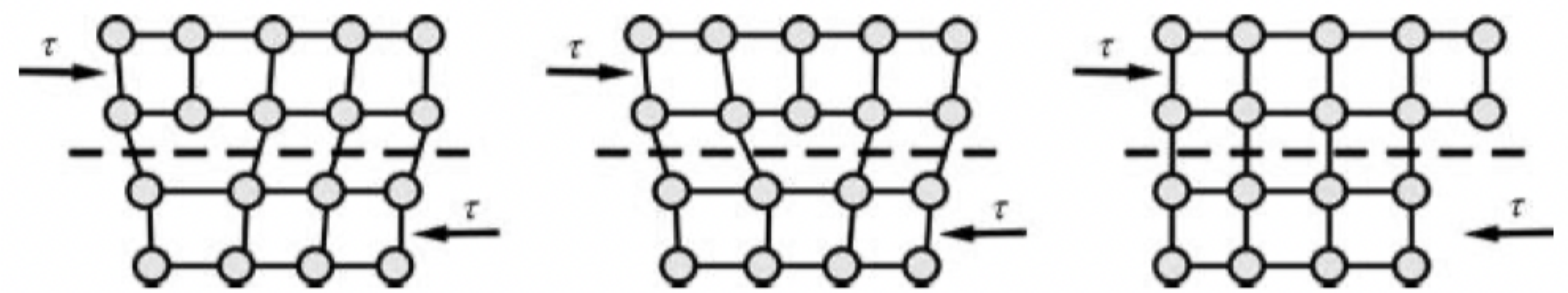


Figure 2: Dislocation for an edge dislocation along a slip plane (τ is shear stress).

With progressive deformation, the dislocations that arise and migrate during deformation pile up with an increasing degree of deformation, mutually block each other, and are finally no longer capable of gliding (termed Lomer–Cottrell dislocations).

Other dislocations migrate up to the grain boundary, where they are stopped. Such a pile-up of dislocations at obstructions results in the strain hardening of the material.

The dislocation lines, when driven back and forth by the alternating loads, will band together to form distinct persistent slip bands (PSBs). These bands then propagate along the primary slip plane, when the amplitude of plastic deformation lies within a certain range. Characteristic for the morphology of PSB dislocation structures are ladder-like dislocation structures as shown in Figure 3.

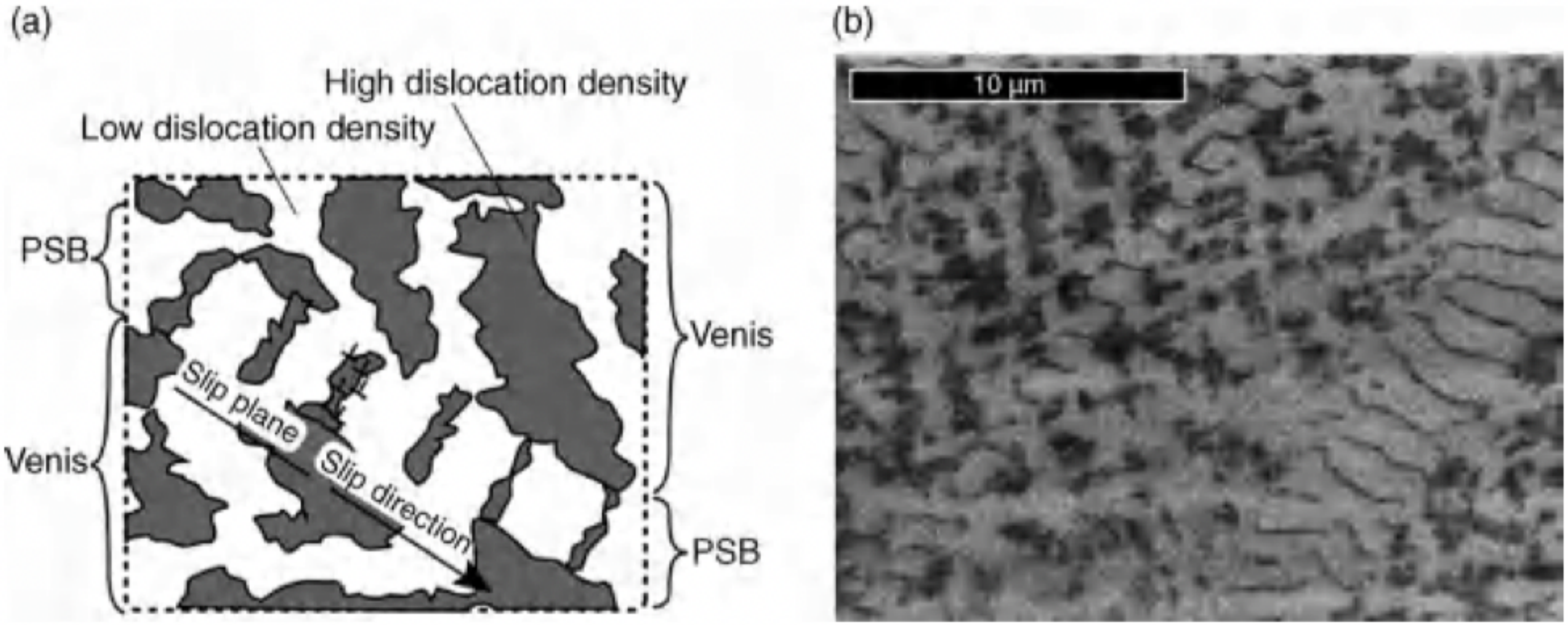


Figure 3: (a) Ladder-like structures of persistent slip bands (PSBs) along the primary slip planes and (b) Transmission electron microscopy image of a Ni poly-crystal following fatigue testing with distinct PSBs.

In this case, the break-through of slip bands on the surface results in the formation of pushed-out and drawn-in slip-off zones (shear lips), which – due to their stress concentration represent potential regions for the formation of cracks.

As a result of the dislocation motion, defects form in the crystal lattice which, under progressively greater mechanical loading, grow to form microscopic holes (voids), thus weakening the mechanical stability of the structure in the edge zone of the part.

Typical of surface fatigue is cracking that runs parallel to the surface, joining the voids and breaking platelet-shaped particles out of the surface. The surface then appears to be “destroyed” due to the cracking and the pitting left behind by the delaminating particles.

The formation of wear particles therefore assumes a certain incubation time, during which no measurable wear takes place. As compression stresses of varying magnitude are transferred by a lubricating film, surface fatigue may occur in dynamically loaded plain bearings, and also in elastohydrodynamically lubricated gearwheel pairings.

Protection against surface fatigue is offered by the same measures as for volumetric material fatigue and, above all, the application of compressive stresses to the edge zone of the component surface has proven to be of value.

Mechanical surface treatment processes (such as shot-blasting) or thermochemical diffusion processes (such as nitriding or carbonization) can be employed in this case.

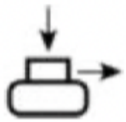
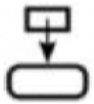
Polished surfaces show a better stability against surface fatigue, as they exhibit fewer notches that would represent potential regions for the formation of cracks.

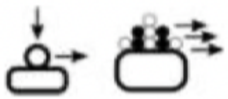
TYPES OF WEAR

Wear processes are classified according to their type of motion, tribological loading, and system structure (in particular of the materials concerned) into different types of wear, in which the different mechanisms of wear usually occur simultaneously as shown in Table 1.

Based on an analysis of the different forms of wear (type and form of the wear particles, alterations to the surface), it is possible to determine which wear mechanisms are involved.

Table 1: Types of wear and frequently occurring wear mechanisms.

Elements of system structure	Tribological load (symbols)	Wear type	Effective mechanisms			
			Adhesion	Abrasion	Surface fatigue	Tribochemical reaction
Body (1) Intermediate material (3) (hydrodynamic) Body (2)	Gliding rolling (no slip) Rolling (slip) Impact 	—			X	X
Body (1) Body (2) (Solid friction, boundary friction, mixed friction)	Sliding 	Sliding wear	X	X	X	X
	Rolling (no slip) Rolling (slip) 	Rolling wear (no slip) Rolling wear (slip)	X	X	X	X
	Impact 	Impact wear	X	X	X	X
	Oscillating 	Fretting wear	X	X	X	X

Elements of system structure	Tribological load (symbols)	Wear type	Effective mechanisms			
			Adhesion	Abrasion	Surface fatigue	Tribochemical reaction
	Oscillating 	Fretting wear	X	X	X	X
Body (1) Solid particle (2)	Sliding 	Scoring abrasion, Erosion		X		X
Body (1) Body (2)	Sliding 	Particle sliding wear, three-body-wear		X	X	X
Solid particle (3)	Rolling (slip) 	Particle rolling wear (slip)		X	X	X
	Grinding	Grinding wear		X	X	X
Body (1) Fluid with particles (2)	Streaming 	Flush wear (erosion wear)		X	X	X
Body (1) Gas with particles (2)	Streaming 	Sliding jet wear (erosion wear)		X	X	X

Elements of system structure	Tribological load (symbols)	Wear type	Effective mechanisms			
			Adhesion	Abrasion	Surface fatigue	Tribochemical reaction
Body (1) Fluid or Gas (2)	Impact  	Impact jet wear, Inclined jet wear		X	X	X
	Streaming Vibrating 	Material cavitation, Cavitation erosion			X	X
	Impact 	Droplet erosion			X	X

WEAR PARAMETERS

The analysis of wear allows the determination of direct, normalized, or indirect wear parameters.

Direct wear parameters describe alterations in the form or mass of a system component, whereas normalized parameters are derived from direct parameters. These represent a normalized value, in relation to a reference value, such as length and/or time, and are also referred to as “wear rates”.

These parameters are used preferentially in connection with tribological systems, as their information value in respect of the tribological system is greater than that of direct parameter values.

To arrive at a well-defined loss of functionality in advance is based on the measurement of indirect parameters, where the information refers to a component or to the entire system in respect of required time or throughput.

The parameters that can be measured are listed in Figure 4. Recommendations for the use and selection of wear parameters are also offered which are helpful when designing the methods of testing.

Direct	Alterations to the form or mass of a tribological component
Normalized	Direct measurement, normalized to a reference value
Indirect	Statement of loss of functionality of a tribo element or system, in respect of required time or throughput

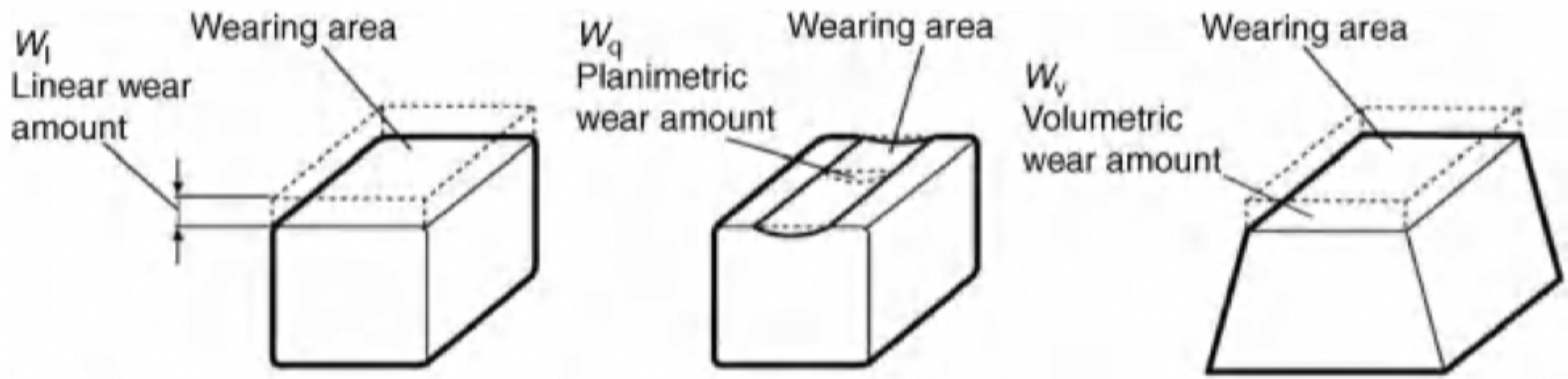


Figure 4: Definition of direct wear parameters and an overview of normalized wear parameter measurements.

Amount of wear	Linear	Planimetric	Volumetric	Mass-like	Designation
	W_L	W_q	W_V	W_m	
Reference value	m	m^2	m^3	kg	
Load duration, t (h)	$W\frac{L}{t}$	$W\frac{q}{t}$	$W\frac{V}{t}$	$W\frac{m}{t}$	Wear velocity
Load distance, s (m)	$W\frac{L}{s}$	$W\frac{q}{s}$	$W\frac{V}{s}$	$W\frac{m}{s}$	Wear distance ratio
Throughput, z (m^3) or kg	$W\frac{L}{z}$	$W\frac{q}{z}$	$W\frac{V}{z}$	$W\frac{m}{z}$	Wear throughput ratio