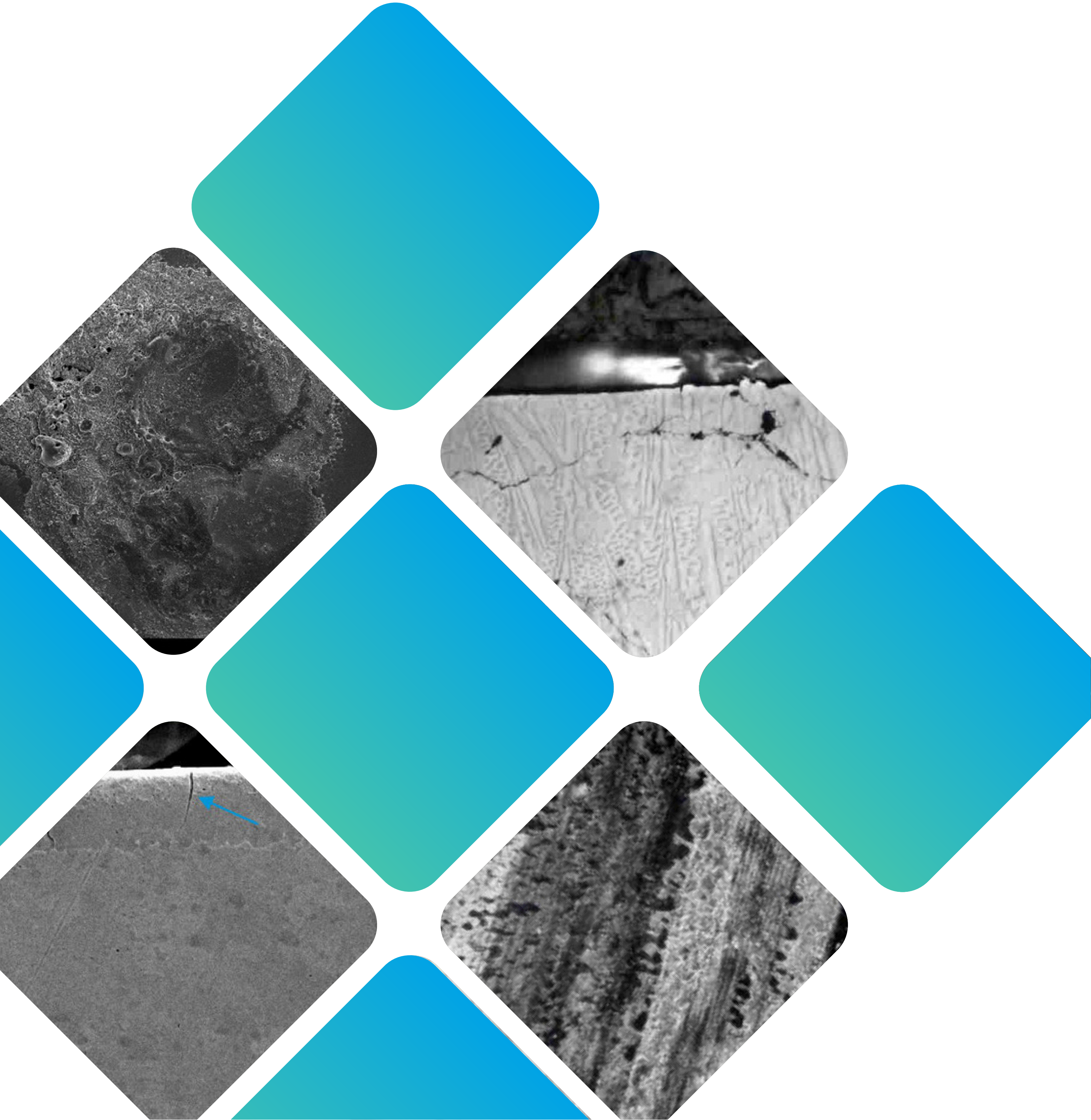
HEF NORTH AMERICA | **Surface materials engineering**

Tribological solutions for different types of wear



HEF's business is surface materials engineering: We are a vertically integrated, multi-specialist, contract provider of surface treatments and components; a leader in tribology, a challenger in photonics and an emerging player in hydrogen technologies. HEF Group focuses on 5 target sectors: mobility, construction, decarbonised energy, aerospace & defence, and medical.

TRIBOLOGICAL PROBLEMS AND SOLUTIONS for WEAR due to ADHESION/SEIZING

Under the influence of high temperature and/or high working pressure and high speed, joints (points of adhesion, welding) can occur between the asperities of the materials in contact (1).

In this situation, continuation of the movement necessitates:

- Shear and rupture of newly formed joints (this is the most favourable case, resulting in less wear) (1b)
- Or, if the joints are sufficiently resistant, fragments of one of the materials in contact may break; and this will cause more extensive damage. (1c)

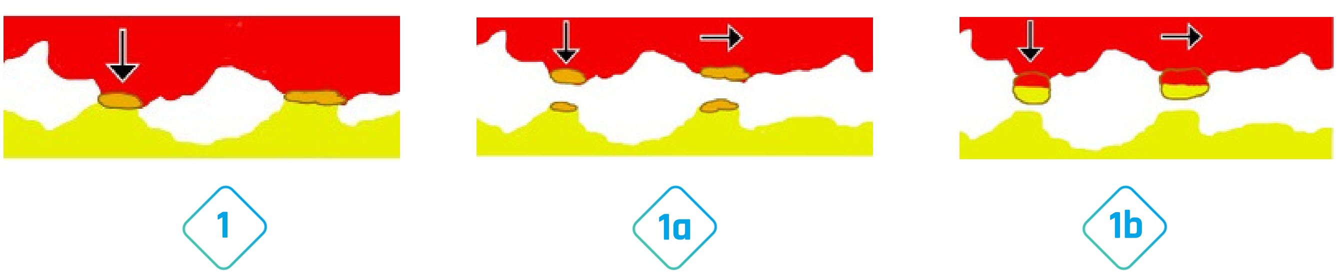
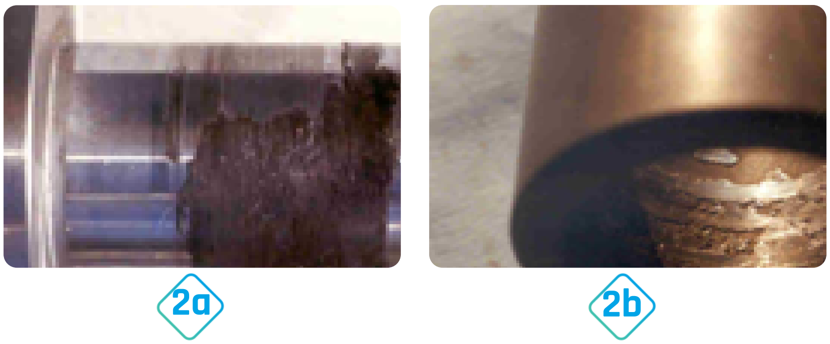


Figure 1: The mechanism of adhesive wear

In extreme cases, when joint density exceeds a critical value, movement is blocked. This is the seizure phenomenon As a rule, adhesion is identified by the fact that the material of one of the surfaces in contact, transfers to and adheres on the counterpart. An example is shown below. In this example, a hard-chrome coated shaft failed catastrophically due to adhesion of its coating on the bearing surface.



Figures 2a and 2b: Hard-chrome coated steel shaft, (a) and bearing with chrome residues (b)

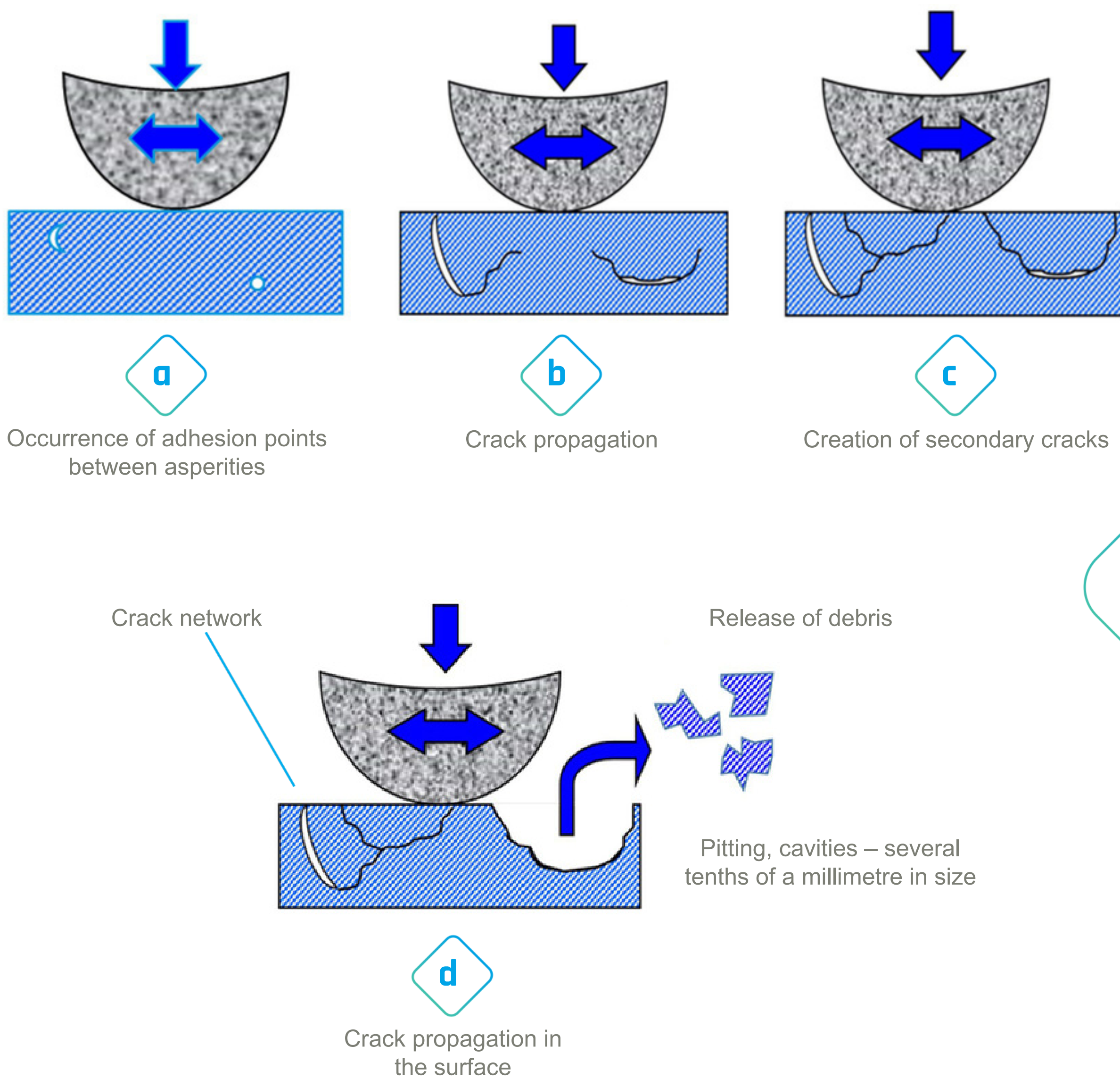
Our solutions

- We select materials with low metallurgical compatibility to limit the risk of adhesion
- We apply surface treatments (deposition, diffusion or conversion)
- We provide an appropriate concept design with regard to topography, roughness, as well as play and alignment of the surfaces
- We use materials with self-lubricating properties
- We apply coatings based on solid lubricants
- We use porous surfaces impregnated with lubricants
- We offer improved lubrication and dissipation of system energy

SURFACE FATIGUE

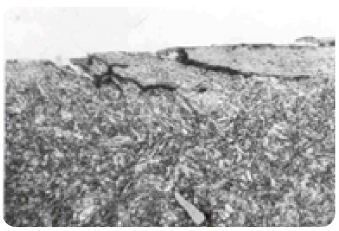
The **surface fatigue** phenomenon is characteristic of systems subject to cyclic load in operation, such as sliding, rolling or impact (specifically, raceways, gearing, to cite two examples). Cyclic load induces stresses that accumulate at or below the surface. This in turn triggers a failure consisting of micro-pitting (also referred to as micro-spalling or frosting) of the surface layers of the material. With each cycle (of the system), the stresses applied on the material generate an accumulation of plastic micro-deformations at or below the surface. As micro-deformations accumulate, cracks appear and propagate. When they meet, these cracks cause surface failure due to the occurrence of micro-spalls, which detach and result in surface failure due to spalling (pitting). In other words detachment and release of material fragments (debris).

Figure 3 below illustrates this process of surface fatigue and pitting

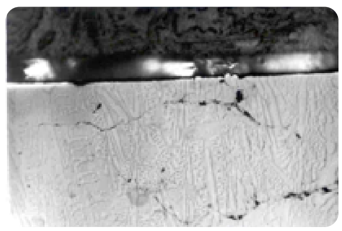


Figures a and b: Surface-initiated fatigue (a) and sub-layer fatigue (b)

Figure c: Pitting (spalling) on gear teeth



a



b

c

Our solutions

- We reducing contact pressure
- We select materials with appropriate mechanical properties
- We introduce a field of residual compressive stress at the surface: mechanical strain-hardening operations (shot-peening, roller burnishing) or diffusion treatments (nitriding, case-hardening)
- We provide an appropriate concept design with regard to topography, roughness, as well as play and alignment of the surfaces
- We apply surface treatments to reduce the system's coefficient of friction
- We offer improved system lubrication
- We use surface treatments that retain lubricants
- We select materials with homogeneous, defect-free microstructures

ABRASION

Abrasive wear can occur through two different mechanisms: Two-body abrasion and three-body abrasion. Two-body abrasion results from the action of irregularities or asperities present on one surface which "scrape" the other surface in relative motion. With three-body abrasion the effect is caused by the presence of a third body (often debris, dust or abrasive particles) between the moving surfaces.

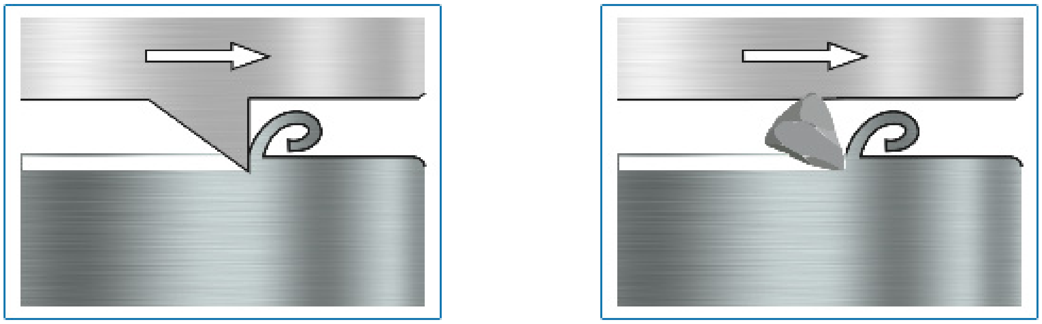


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Figure 8: Two-body abrasion and three-body abrasion

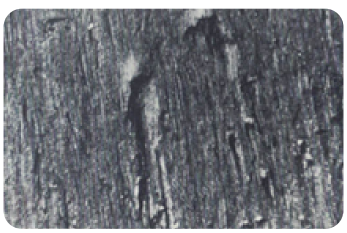
This means that it is possible that the third body will be made up of fragments (debris) generated by the two-body abrasion process. In this case, the system, which starts with a two-body abrasion process, develops into a three-body abrasion system.

Depending on the characteristics of the system (environment, nature of the materials, characteristics of the surfaces, etc.), two modes of failure can be observed:

- **Plasticdeformationofthematerialcaused by the action of the abrasive substance:** This is abrasion by deformation (Figure 9).

- **Tearing of the material caused by "machining" of the surface:** This is abrasion by removal (Figure 10).

In both cases, the striations of abrasion are sometimes isolated; they vary in length and they may stop abruptly. In the case of abrasion by removal, the striations can be interrupted and scratch the surface of the material in a widespread manner. An example of this case is shown in Figure 11.



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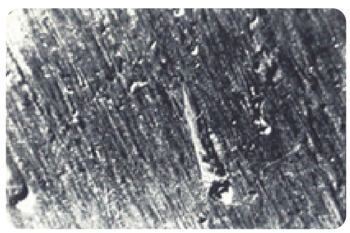

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Figures 9 and 10: Abrasion by deformation (9) and abrasion by removal (10)
Figure 11: Surface completely scratched by the abrasive process

Our solutions

- We prevent abrasive material from entering the system
- We provide a design with grooves/cavities to trap fragments and remove them from the contact zone
- We provide an appropriate concept design with regard to topography, roughness, as well as play and alignment of the surfaces
- We select hard materials or use of hardening heat treatments
- We apply thermal and/or thermochemical treatments that significantly increase surface hardness

EROSION

The erosion phenomenon is somewhat similar to the three-body abrasion phenomenon. In this case, surface failure is caused by impact of a third body moving relative to the attacked surface. The main difference is that erosion occurs when the abrasive material is transported by a fluid. The nature and severity of the phenomenon depend on various factors, such as particle size, particle shape, particle hardness, etc. One important factor in erosion phenomena is the incidence angle of the particles relative to the attacked surface. The incidence angle can promote scratching of the surface (ductile erosion) at low incidence angles or it can promote impact of particles against the surface (brittle erosion) at high incidence angles. In the first case, the hardness of the attacked surface is the determining factor for the resistance of the system. In the second case, a high-tenacity material is preferred in order to withstand the impact of erosive particles.

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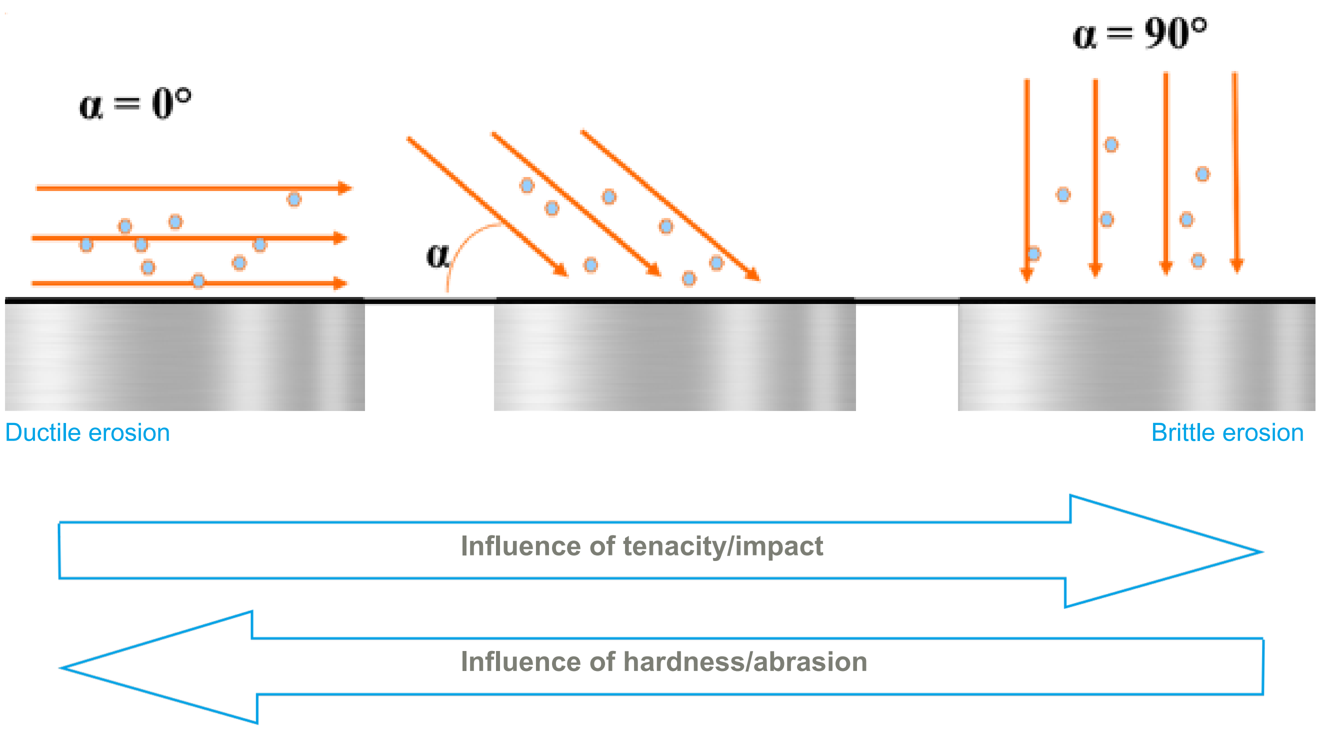

Figure 12 illustrates these situations.

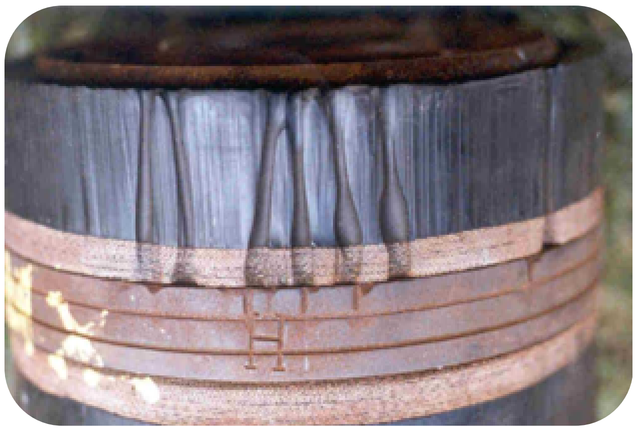

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Figure 13 shows a pump piston damaged by erosion. In this example, a pump displaced a fluid charged with aluminium oxide.

Our solutions

- We prevent erosive material from entering the system
- We use thermal and/or thermochemical treatments to increase the hardness of the attacked surface
- We select materials with a high degree of hardness, appropriate for the application
- We modify the speed and/or angle of attack of erosive particles
- We select deformable and/or elastic materials, appropriate for the application

CAVITATION

Cavitation wear is characterised by accumulation of micro-cavities on the surface. Cavitation can be destructive when the cavities open on the other side of the part (hole formation).

This phenomenon occurs when parts come into contact with **fluids** and are in **relative motion.** Based on the geometric characteristics of the system, the fluid may be locally in a vacuum. In this case, the gas dissolved inside the fluid can create bubbles that attach to the surface. When these bubbles implode, they exert a tensile stress, which over time can result in local fracture of the material and a "spooning" removal of the material.

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Figure 14: Cavitation in a piston liner

Our solutions

- We prevent solid impurities in lubricants
- We prevent sudden changes in pressure and/or temperature (this involves work on part geometry)
- We prevent effervescence in the liquid/lubricant
- We use treatments to increase the hardness of the attached surface
- We apply thick elastic coatings

FRETTING (WEAR / CORROSION / FATIGUE DUE TO CONTACT WEAR)

The phenomenon of fretting is typical of systems that operate with high-frequency, low-amplitude relative motion. Even the elastic deformation of certain system components may be sufficient to cause this type of wear. A good example is corrosion that occurs between the leaves of a leaf spring, induced by the relative motion of the surfaces of the leaves in contact, due to their elastic deformation in operation. Wear induced by fretting is particularly significant for structures and equipment subject to vibration. This issue is critical for the aerospace industry.

The fretting effect may have different consequences, depending on the materials, the system conditions and the operating equipment.

• **Fretting wear:** When surfaces in contact generate fragments/debris (abrasive wear or adhesive wear) and there is no exit possibility, the fragments/debris remain in the system and cause abrasive wear.

- **Fretting / contact corrosion:** In this case, the debris that forms is both mechanically and physically-chemically transformed because of the system's operating conditions. The debris is transformed into oxide particles (usually these particles are much harder than the original material) and these particles accelerate the wear and oxidation of surfaces.

- **Fatigue due to fretting:** Forces acting on the surface due to the phenomenon of contact wear can cause cracks. Given the cyclic repetition of the system's movements, these cracks will propagate in various directions in the material. Ultimately micro-spalling will occur on the surface of the components.

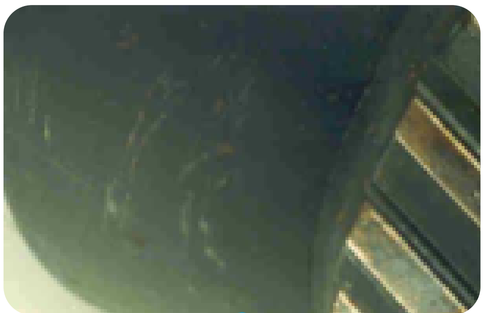

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Figure 15: Fretting corrosion on a clutch hub

Our solutions

- We eliminate vibration and relative motion on the microscale
- We use surface treatments that introduce compressive stress on the surface
- We select friction-reducing surface treatments
- We select suitable surface treatments to prevent oxidation of fragments/debris
- We provide a topography designed to trap or evacuate fragments/debris

WEAR DUE TO OVERSTRESS

Wear due to overstress occurs when the loads applied to the surface exceed the material's resistance capacity. This, in turn, results in faults that are usually easy to identify. This type of wear often results in catastrophic failures that considerably reduce the efficiency of the system, or completely interrupt operation. This type of wear can occur suddenly. It is influenced by alteration of some variable in the system (for example, interruption of lubrication systems or refrigeration systems), or it may be the consequence of a cumulative effect over long-term operation of the components. Essentially two types of wear are caused by overstress, as shown on the following page:

- Plastic deformation and creep: cause geometric and dimensional changes in materials (usually with no loss of mass). Plastic deformation and creep primarily occur when the average contact pressure in the system is high or where there is excessively high pressure at a specific point in the system. In either case, excessive pressure exceeds the elastic limit of the material, and this can increase the coefficient of friction or the temperature of the system. Consequently, plastic deformation of the surface material can cause embrittlement (strain hardening), which reduces the component's fatigue resistance.

- Fracture and material loss: characterized by crack formation, release of fragments/debris and deterioration of the surface. In this case, the stresses applied to the surface are excessive relative to the mechanical strength of the material.

Figures 16 and 17 show two comparatively common examples of system failure due to excess stress.

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Figures 16 and 17: A polymer bearing showing plastic deformation due to excessive stress (16) and a hard-chrome coated steel raceway with cracks and stripping of the chrome layer (17)

Our solutions

- We select materials with the right mechanical properties for the application
- We reduce contact pressure
- We offer an appropriate design in terms of play and alignment of the surfaces
- We provide treatments that promote the conformance of surfaces
- We provide treatments that reduce the coefficient of friction
- We offer improved lubrication and dissipation of system energy

TRIBOCORROSION

Tribocorrosion is a phenomenon that occurs when friction surfaces are in an environment that promotes corrosion or oxidation. These loads promote wear on the surface by continuously or intermittently removing the surface oxide film, with which the surface was originally coated. From this point on, the phenomenon is governed by competition between the formation of a new surface oxide film and the re-exposure of the base material subsequent to the wear-induced removal of the film. This phenomenon can have negative consequences for the system, such as removal of material from the surface (degradation of the surface condition, generation of fragments/debris, which accelerates swear) or accelerated degradation through corrosion (particularly if the film removed had a passivation function).

Figure 18 shows a typical example of **tribocorrosion wear**, where an engine valve is subject to oxidation through the action of combustion gases and, as a result, is damaged by the hard fragments/debris formed from the oxides.

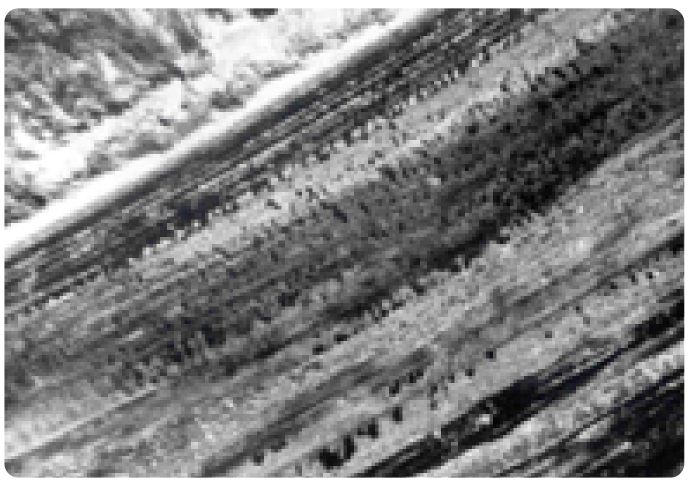

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Figure 18: Tribocorrosion on an engine valve

Our solutions

- We select a coating or surface treatment that is resistant to the chemical environment
- We use tribological coatings to protect against wear and reduce friction
- We offer improved lubrication and dissipation of system energy
- We select appropriate lublicants for the lubricated contact
- We provide an appropriate concept design with regard to topography, roughness, as well as play and alignment of the surfaces

CORROSION

The phenomenon of metal destruction by means of chemical or electrochemical action is referred to as corrosion.

Corrosion can be induced by a wide range of causes. The main forms of corrosion can be classified as follows:

- Uniform corrosion: Characterized by an attack on the entire surface of the metal. Examples of uniform corrosion are rusting of structural steel immersed in water or oxidation of steel exposed to high temperatures.
- Pitting corrosion: Occurs through very fine, scattered points on the attacked surface, which primarily develop at depth (towards the core of the material) rather than spreading laterally over the surface. A typical example of pitting corrosion is stainless steel exposed to sea foam or seawater.
- Intergranular corrosion: Localized in a manner that is similar to that of pitting corrosion, consists of the selective attack on the contours of the grains in the structure of the metal. The attacked material takes on an opaque appearance, loses its metallic sound and becomes brittle.
- Stress corrosion: Occurs in parts subject to mechanical stress and that are exposed to a corrosive environment. It generates slowly propagating cracks. This type of corrosion occurs more frequently in stainless steels, brass and light alloys.
- Differential aeration corrosion: Occurs when an area of the metal is exposed to different concentrations of oxygen or dissolved gases. This in turn causes a electric potential difference between the parts that are aerated differently. The result is corrosion of the metal. This type of corrosion is frequently observed in metal structures with immersed parts or confined areas.

The factors that interfere with corrosion phenomena and the classification of these factors into four groups are listed below:

- Chemical factors: Reagent concentration, oxygen content, pH, temperature, etc.
- Electrochemical factors: Differences in electrical potential between the materials and the environment, combination of materials, etc.
- Metallurgical or structural factors: Composition of the metal or alloy, manufacturing processes, impurities, heat treatments, strain hardening, etc.
- Mechanical factors: Residual stresses, mechanical loads, surface conditions, etc.

Our solutions

- We select the right materials (for high temperatures, chemically aggressive environments, etc.)
- We offer an appropriate election of surface treatments
- We use coatings with anti-corrosive properties
- We appropriately select the heat treatment process to be implemented

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