What is Wear?

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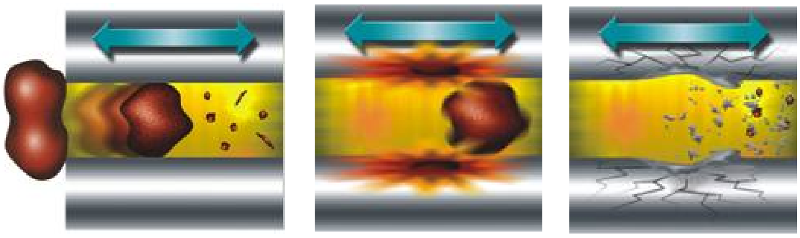
It is generally recognized that contamination of lubricating and hydraulic oils are the primary cause of wear and component failures – some say 70-80 percent of all failures. The purpose of the oil is to ensure that component surfaces are kept clean, sufficiently cooled and to avoid metal-to-metal contact between surfaces. However, contaminants can prevent the oil from doing what it is designed to do. Wear debris or intruding particles and water can initiate a chain reaction of wear.

Even though a component surface might seem smooth, it actually has many tiny asperities and “high spots”. The load applied to the surfaces will be transferred through these “high spots”, causing very high local pressure forces, thus increasing the risk of metal-to-metal contact. Furthermore, the “high spots” and “valleys” in the surfaces can hold particles, which will result in intense wear.

The hardness and finish of the surfaces are very important factors for the ability to withstand wear, but other factors like load, speed, temperature and, of course, the oil film strength and oil cleanliness play equally important roles.

In the following you will find descriptions of destructive wear modes that correspond to approx. 70 percent of why a typical component fails. This can result in wear rates accelerating 10,000 times more than intended by the machine designer.
On page 6 you will also find a list of typical dynamic oil film thickness in different machine components.

Abrasive wear



Abrasive wear occurs in sliding contact and is also known as grinding, because the wear mechanism is basically the same as the machining, grinding, polishing or lapping used for the shaping of materials.

Two-body abrasive wear occurs when one surface (usually harder than the other) cuts material away from the other surface, although this mechanism very often changes to three-body abrasion as the wear debris in turn act as abrasive particles between the two surfaces. A similar situation occurs when a particle (e.g. silica dust) enters a clearance between two component surfaces, when the clearance is equal to the particle size.

Abrasive particles such as silica dust can come from the oil system’s environment (airborne); or particles can be generated within the oil system through wear, “high spots” breaking off, corrosion etc. The abrasive particles can have a grinding effect when sticking to one of the surfaces - or a lapping effect where the particle tumbles over the surfaces producing a series of notches and cavities as opposed to a scratch.

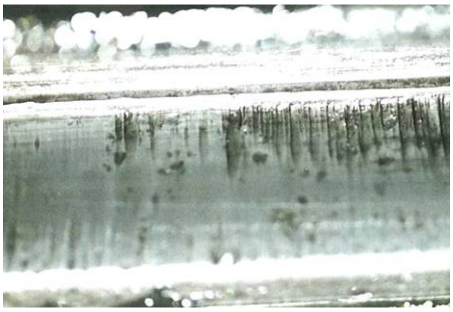
A particle can break into smaller particles, which in turn become harder due to the processes of work-hardening (similar to hammering or rolling steel). These small and numerous particles are even more dangerous, as they can enter even finer clearances, or get squeezed, accelerating further abrasive wear.

Abrasive wear is often seen both in hydraulic oil systems in servo valves, proportional valves, cylinders and pumps - and in lubrication systems in bearings, bushings, pistons/liners etc.

Influencing factors:

- particles in the oil; the concentration, size and hardness of them
- oil film thickness (depending on load, oil viscosity and component speed/rpm)
- surface hardness
- component alignment

Photos show abrasive wear on gear tooth and on rolling element bearing



Adhesive wear

Adhesive wear is also known as scuffing or galling, and may occur under boundary lubrication conditions, when two surfaces get ”bonded” locally during a sliding movement (metal-to-metal contact). Excessive load, low velocity movements or reduced oil film/viscosity are the typical causes of adhesion.

This metal-to-metal contact may result in material transfer between the surfaces, similar to that of spot welding. When the two surfaces separate, the bonded spot breaks off and removes material from the surfaces, causing fractures, cavities and tiny abrasive particles which are released.

Due to the cold welding process, the released particles are harder than the surfaces from which they originate and can thus cause great damage and speed up abrasive and erosive wear. For adhesive wear to occur it is necessary for the two surfaces to come in close, solid contact with each other, i.e. without any carrying oil film in between. Consequently, a clean lubricating oil film is the best way to avoid or reduce the risk of adhesion to occur.

Usually, particle contamination in the oil will not cause adhesive wear, but insufficient oil viscosity and water in the oil will. Oil has an ability to turn “solid” in local pressure points, e.g. in rolling element bearings, thus protecting the moving surfaces. This momentarily pressure induced viscosity increase is called elasto-hydrodynamic lubrication. Water does not have this ability, which results in the carrying film braking and the moving surfaces getting into contact with each other, leading to adhesive wear, i.e. “spot welding”.

This can be seen in lubrication systems with rolling element bearings, between pistons/liners or in heavy loaded gears. Adhesive wear is seldom seen in hydraulic systems.

The influencing factors are:

- oil film thickness and viscosity
- high loads, slow speed
- gear tooth size
- surface roughness
- improper use of anti-scuff and AW/EP additives

Photo shows adhesive wear (scuffing) on gear teeth

Corrosive wear

Corrosive wear occur when there is a combination of a wear situation (abrasive or adhesive) and a corrosive environment.

Most lubricants get acidic over time due to the degradation/oxidation processes (catalysed by heat, water, metal particles etc.). Water or moisture reacts with the acid in the oil to increase the corrosive potential and further stimulate the attack on the metal surfaces. The corrosive wear results in a removal of metal, mostly in the form of ferrous oxides, also known as rust particles. The rust particles are hard and abrasive and in combination with other wear particles, they can expose fresh metal to further corrosion - speeding up the process of abrasive wear.

The rate of material loss can be very high, many times more than what would result from the individual processes of wear or corrosion alone. This is because loose corrosion particles are easily removed by wear to continually reveal fresh metal beneath, which can corrode quickly. Likewise, stable oxide films that would normally limit corrosion (in the absence of wear) are instantly worn away.

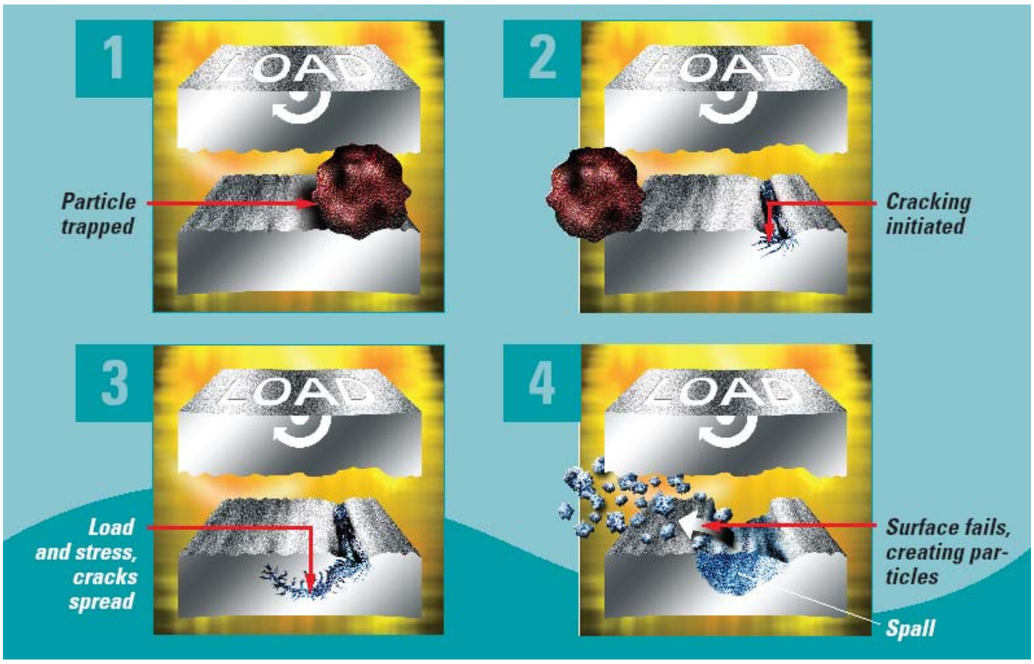
Typically the corrosion rate (rust) doubles for every 10 $^{\circ}$C increase in temperature.

Corrosive wear is seen in both hydraulic and lubrication systems where moisture/water is present either due to condensation or ingress (leaking seals, cooler etc.).

Applications prone to corrosive wear are: steam turbines, steel mills, paper mills, marine applications, water cooled oil systems etc.

Techniques to reduce corrosion:
- oil contamination control (remove water and acid)
- use oil with corrosion inhibitors and alkalinity reserve
- choose the correct metallurgy
- use protective cathodic plating (e.g. Zinc)

Fatigue wear



Fatigue wear on components in oil systems is usually initiated by cracks and notches, which are the result of particles being trapped and squeezed in the clearance between two surfaces (abrasive wear).

Operation of the components being lubricated with oil will cause metal stress and may lead to cracks spreading under the surface, due to repeating load and pressure. The result is metal fatigue, meaning that the surface will eventually fail and the structure collapse, releasing lots of particles into the oil. In this state of fatigue wear large craters or spalls across the surface can be seen with the naked eye (see photo below).

The release of wear particles starts a chain reaction, accelerating other wear processes. Again, the most dangerous particles are those with roughly the same size as the dynamic clearance, because they get trapped and instigate the formation of cracks.

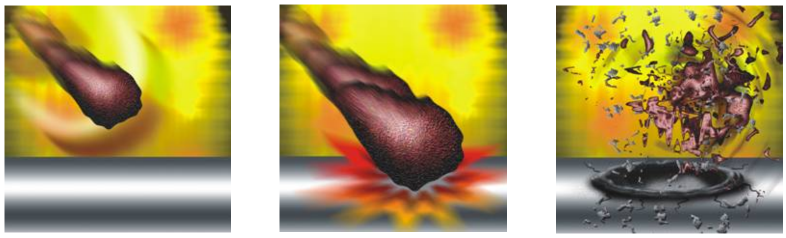
Fatigue wear is mostly seen in oil systems with rolling element/ball bearings, cams, rollers and gears exposed to cyclic stress variations e.g. at pitch line of a heavy loaded wind turbine gear.
Fatigue wear can also be caused by extreme material stressing (tiredness), caused by many contractions and expansions, e.g. due to thermal changes, but this is not typically seen on components in hydraulic and lubricating oil systems. If the load is doubled the gear or bearing life is cut to one tenth of the design lifetime.

In order to control surface fatigue the following can be done:

- increase oil film strength (viscosity)
- reduce surface roughness
- maximize surface hardness
- avoid particle contamination
- avoid moisture/water in the oil

The photo below shows fatigue wear on wind turbine gear (severe surface pitting/grinding temper).

Erosive wear



Erosion means that the surface gets deteriorated and porous, and it is often found in oil systems with high oil pressure and high flow velocities. The flow carries particles which impinge the component surface or edge, causing a “sand blasting” effect. Erosion can also be caused by chemical attacks, e.g. by acids.

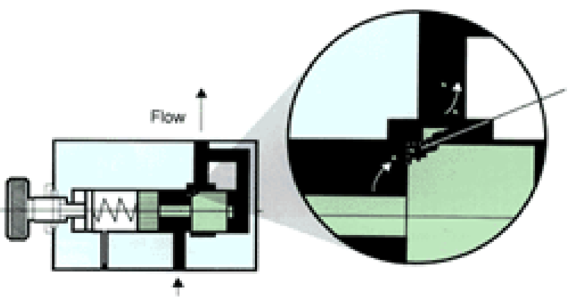
In the process of erosion, material is blown and washed away from the surface, leaving it very open and fragile, as well as introducing many particles to the oil. Erosive wear most commonly occurs in hydraulic systems with servo and proportional valves, because the fine clearances in these valves result in high oil velocity and pressure.

The effects of erosion can be seen in lubrication and hydraulic oil systems as component leakage, lower efficiencies and as high particle counts in the oil.

Cavitation Erosion: Cavitation can also cause erosion, when water is present in the oil (as vapour). The pressure increase causes the vapour/bubbles to collapse - they implode. This releases very large forces (like a microjet), which blows particles off the surface, causing surface porosity and erosion.

Machine components typically affected by erosion:
- control valves
- pumps
- actuators
- sometimes also seen on journal bearings and rolling element bearings

Erosion wear on control valve



Dynamic oil film thickness

The following shows typical dynamic oil film thickness when components are operating. It is the contaminating particles which have the same size as the clearance or slightly bigger that are the most dangerous ones. We should limit the ingress of these and remove as much as possible by filtration.

	Oil film thickness:
Rolling element bearings / ball bearings:	0.1 – 3 microns
Journal, slide and sleeve bearings:	0.5 – 100 microns
Engines, ring/cylinder:	0.3 – 7 microns
Gears:	0.1 – 1 micron
Servo and proportional valves:	1 – 3 microns
Gear pumps:	0.5 – 5 microns
Piston pumps:	0.5 – 5 microns
Hydraulic cylinders:	5 – 50 microns
Dynamic seals:	0.05 – 0.5 micron