Magazine Article

Wear Rates Impact Maintenance Priorities

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A lubrication program is a critical aspect of machinery health management. No one questions the direct relationship between good lubrication practices and long machine life. This fact is universally understood. It is intuitive. Lubrication provides low friction and enables long machine life.

What are the maintenance priorities at your facility? We all have too much to do with too few resources. If you can perform only a few maintenance tasks, which ones will provide the greatest value?

The first step in solving a problem is to identify the biggest challenges. Then maintenance and management can work together toward effective solutions.

Abnormal wear is the opposite of good health for machinery. A high wear rate implies poor machinery health. So if you manage wear rates, you will directly manage your machinery health. Focus your limited resources on the causes of the highest wear rates. That is what machinery health management is all about.

In “Wear for Engineers”[1], the author presents dimensionless normalized wear rates for different mechanisms. Figure 1 shows normalized wear rates for the four mechanisms that cause the vast majority of abnormal wear in industrial machinery today: abrasion, adhesion, fatigue and corrosion.

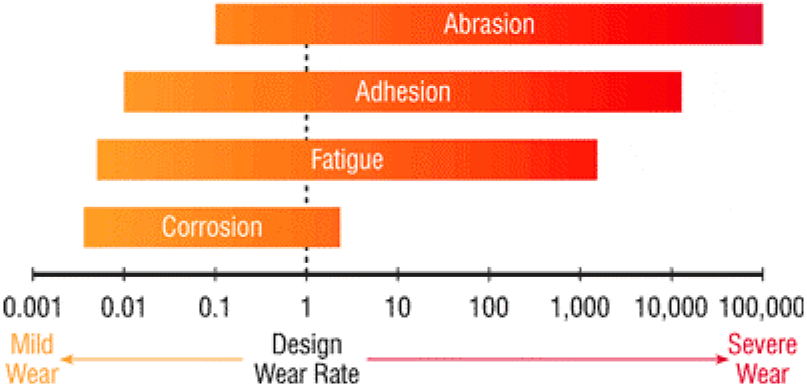


Figure 1. Normalized Wear Rates for Industrial Machinery
(Wear Volume/Distance) x (Hardness/Load)

In Figure 1, the term “design wear rate” has a value of 1 for the conditions that will achieve the manufacturer’s projections for machine life. Industrial machinery is designed to survive about 40,000 hours mean time between failures (MTBF). Increasing or decreasing wear rates can result in far more or far less than 40,000 hours MTBF.

Wear

Mild wear is usually unavoidable. It is not a problem, rather a condition to be expected. Most machines have a finite life and wear at some rate. Mild wear typically means that very small particles, less than five microns, are being worn away. These particles are mostly from the oxide layer that naturally forms on metal surfaces. These particles are easily detected using a spectrometric oil analyzer (for example, atomic absorption or atomic emission spectroscopy).

Severe wear is a serious problem, though controllable. Severe wear involves increasing concentrations of particles greater than five microns. Severe wear debris includes chunks of base metal well beneath the oxide layer on load-bearing surfaces. These larger particles are not easily measured using spectrometric oil analyzers.

Out of seven commonly recognized wear mechanisms (abrasion, adhesion, fatigue, corrosion, cavitation, erosion and fretting) the first four are most often the cause of extremely high or abnormal wear rates.

It is remarkable how many decades (powers of ten) are shown on the normalized wear chart. Wear rates can accelerate 10,000 times more than intended by the designer due to severe abrasion or adhesion. Fatigue can also be an extremely rapid wear mechanism. Corrosion is typically a much slower process, unless combined with one of the other mechanisms. Those combined wear mechanisms can result in a synergistic acceleration to an already excessive wear rate. Corrosion chemically attacks load-bearing surfaces, weakening them and making them progressively more susceptible to wear.

Wear Factors

K/p is the ratio of abrasive wear coefficient, K, and penetration hardness, p. Abrasive wear coefficient, K, depends on saturation and size of abrasives. It carries units of $[(um^3)/(gm \cdot m)]$. Saturation and critical particle size are significant factors]in abrasive wear. Below saturation, it diminishes in proportion to the abrasive concentration. Above saturation, K is constant. Above critical size, K is constant. Penetration hardness, p, has units of (kg/mm2).

The question at hand involves maintenance priorities. If the short list of aggressive wear mechanisms includes abrasion, adhesion, fatigue and corrosion, then how should you adjust your maintenance priorities?

Abrasion

Abrasion is the most frequent and often the most rapid wear mechanism affecting machinery health. Improved air filtration in automobiles is a principal factor in the long life of personal vehicles. Typical useful life for cars today is about 250,000 miles (400,000 kM) compared to 90,000 miles (150,000) kM for cars in the 1970s. Many changes in automobile design have taken place, but one of noteworthy significance is the air filtration. The exclusion of abrasive dust from automobile engines is a major factor in 250 percent longer overhaul intervals.

Abrasive wear is wear by displacement of material caused by hard particles or hard protuberances, or wear due to hard particles or protuberances forced against and moving along a solid surface.

The most serious and frequent cause for abrasion is dust contamination. Silica dust particles cut into steel like a steel knife cuts into cold butter. When dust particles are larger than the clearances between two moving machinery parts, the particle imbeds into the softer surface and then machines a groove into the hard metal surface.

There are three factors to consider with respect to abrasive wear. First is the threshold hardness of the contaminants. If the particles are harder than the load-bearing surfaces, then abrasion has the potential to occur. If the metal bearing or gear surface is harder than the contaminant, then negligible abrasion can occur.

The second factor to consider with respect to abrasion is threshold particle size. If the particle is bigger than the clearance between two moving surfaces, then abrasion can occur, although the greatest wear is typically from particles the same size as the oil film. If it is smaller, then the particle passes with no damage. Keep in mind that the clearances for elastohydrodynamic lubrication under rolling contact (roller bearings and pitch-line rolling in gears) is one to five microns while the clearances for hydrodynamic lubrication (conformal or journal bearings) are typically five to 100 microns.

The third factor is particle concentration or particle count. This factor is not a threshold. Hard particle concentration is typically disproportional to wear rate. For instance, a 10X increase in particles can result in a 50X increase in wear rate. A single particle can abrade a surface many times. Likewise, the temper-hardened wear particles produced can move on to cause even more abrasion.

The author's experience is consistent with the observation that hard particle contamination is the No. 1 problem. For many industrial plants, the objective is less abrasive wear. This is accomplished by less contamination, especially less hard particle contamination.

Contamination control includes the following practices:

- Setting target cleanliness levels (TCLs)
- Frequent particle counting
- Use of desiccating and dirt-removing air breathers
- Use of in-line and off-line filtration t Proper application of seals, access covers and other contaminant entry points
- Best practices for storage, handling and transfer of lubricants
- Awareness training for maintenance and operations staff
- Proactive maintenance actions and validation by measurements

Figure 2 represents wear factors for new and used sandpaper compared to fine and coarse abrasives (sand) not bonded to paper.

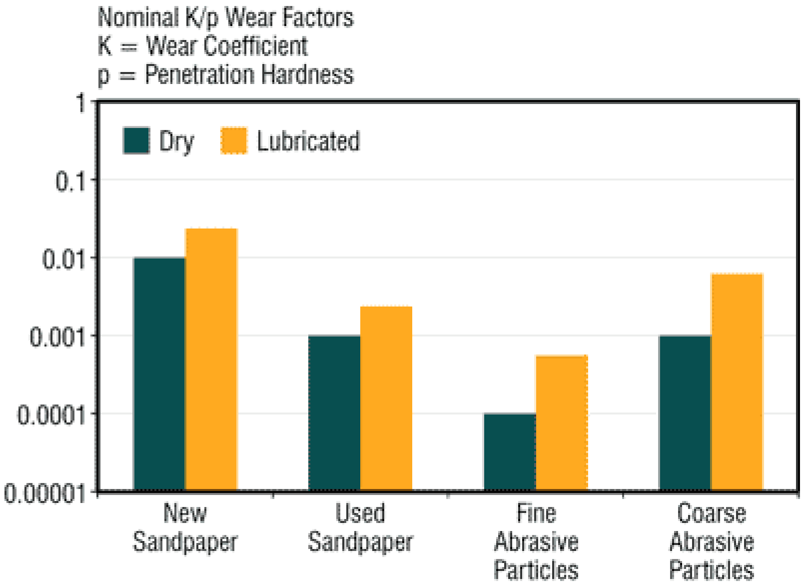


Figure 2. Nominal Wear Factors for Abrasive Wear

One observation is that new sandpaper is 10 times more effective at removing metal than used sandpaper. Another less obvious point is that lubrication doubles the cutting efficiency for the sandpaper and it has a five-fold increase in cutting efficiency for abrasives which are free to rotate. The silica can cause more damage if it can shift its angle of attack while being jostled and turned in the nip between two moving surfaces. An intriguing fact is that the nominal wear factor for lubricated coarse abrasive wear particles is midrange between new and used sandpaper. It is easy to imagine how rapidly a bearing or gear could be worn away by continuous abrasion from sand paper. Contamination control is a must for all industrial machinery health management programs.

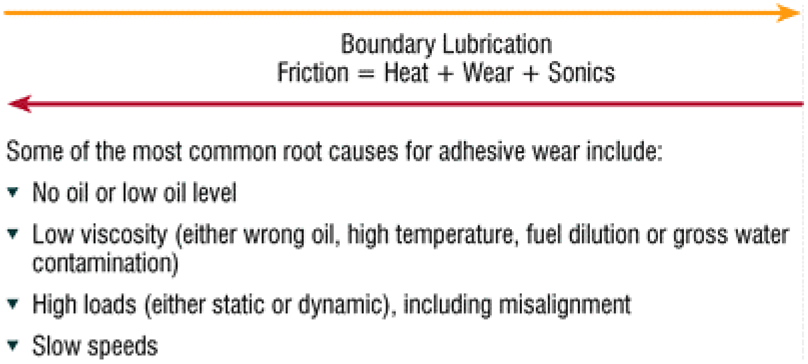
Adhesion

Adhesion is associated with inadequate lubrication, and occurs when loads are transferred from metal to metal. The lubricant film is not sufficient to keep metal surfaces separated. Adhesive wear debris, ultrasonic emission and inadequate lubrication are all observations. Evidence of adhesive wear (particles, sonics, heat, or other indication) requires investigation to properly identify the actual root cause.

Adhesive wear is wear by transference of material from one surface or another during relative motion due to a process of solid-phase welding, or wear due to localized bonding between contacting solid surfaces leading to material transfer between two surfaces or loss from either surface. Adhesive wear is sometimes used as a synonym for dry sliding wear.

Transfer is the process by which material from one sliding surface becomes attached to another surface, possibly as the result of interfacial adhesion.

Some of the most common root causes for adhesive wear include:



Boundary Lubrication
Friction = Heat + Wear + Sonics

Some of the most common root causes for adhesive wear include:

- No oil or low oil level
- Low viscosity (either wrong oil, high temperature, fuel dilution or gross water contamination)
- High loads (either static or dynamic), including misalignment
- Slow speeds

Figure 3. Adhesive Wear Under Boundary Lubrication Regime

Fatigue

Fatigue is directly related to load, normally under rolling contact. Fatigue is common for roller bearings and wear at the pitch line of gears. High load means short fatigue life. Fatigue results when the high shear stresses from rolling contact cause subsurface micro-cracking. These microscopic cracks begin under the surface of the roller or race or gear tooth. The cracks later become interconnected and then intersect the surface. Eventually the particles get released to the oil, leaving behind a delamination or spall defect.

Fatigue wear is the removal of particles detached by fatigue arising from cyclic stress variations, or wear of a solid surface caused by fracture arising from material fatigue.

In a perfectly clean, well-lubricated, ideally loaded machine, the eventual failure mechanism should be fatigue. A bearing or gear that dies of old age dies from fatigue. In this circumstance, the entire bearing would be uniformly pitted. However this is never the case. Selected regions fatigue rapidly while others never show evidence of damage. The pits indicate high-load zones.

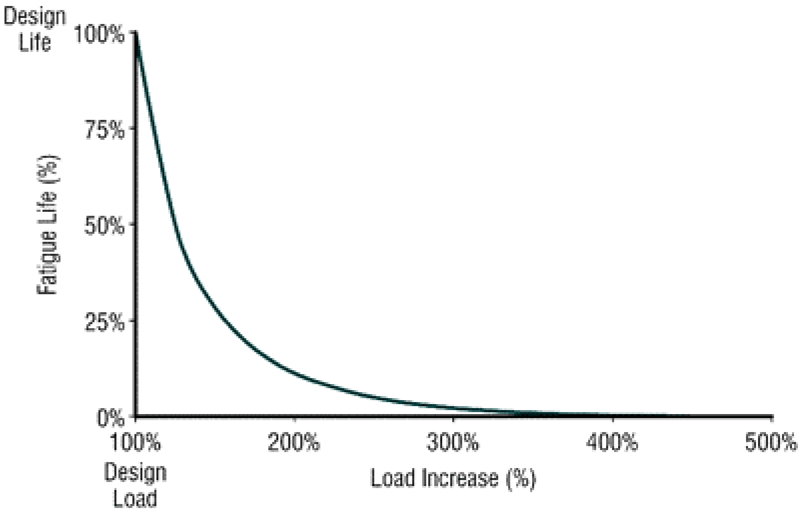


Figure 4. Fatigue Life for Bearings Under Excess Loading Conditions

Figure 4 shows how a bearing or gear with a design life of 40,000 hours will experience fatigue in 4,000 hours if the design load is doubled or 400 hours if it is quadrupled. High loading can be dynamic loading, or g's of acceleration, using vibration analysis, or it can be static loading from gravity, pressure, pre-stress or misalignment.

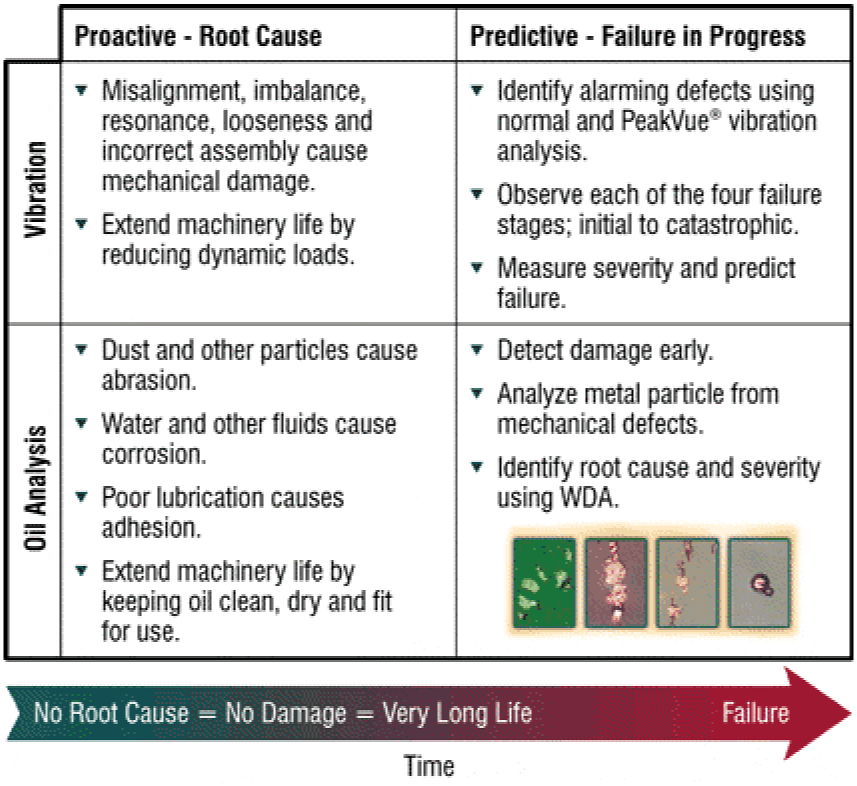
Corrosion

Corrosive wear, also called chemical wear, is caused when corrosive fluids are in sustained, long-term contact with load-bearing metal surfaces. These corrosive contaminants come from cleaning, condensation, rain, process and possibly from badly degraded oil.

Corrosive wear is a wear process in which a chemical or electrochemical reaction with the environment predominates (chemical wear).

Corrosion is often a self-limiting process. For example, water may corrode a metal to the point where the entire surface is oxidized. The resulting oxide layer limits further corrosion. However, this surface oxide is physically weaker than the metal and is easily removed by abrasion or adhesion. This exposes more metal, allowing the process to continue. This example illustrates how synergistic corrosion can be with the other mechanisms.

Water, coolant and corrosive process contaminants are the most common corrosive agents. In addition to particle contamination control, it is important to set TCLs for corrosive agents that can get into the oil.



	Proactive - Root Cause	Predictive - Failure in Progress
Vibration	▾ Misalignment, imbalance, resonance, looseness and incorrect assembly cause mechanical damage. ▾ Extend machinery life by reducing dynamic loads.	▾ Identify alarming defects using normal and PeakVue® vibration analysis. ▾ Observe each of the four failure stages; initial to catastrophic. ▾ Measure severity and predict failure.
Oil Analysis	▾ Dust and other particles cause abrasion. ▾ Water and other fluids cause corrosion. ▾ Poor lubrication causes adhesion. ▾ Extend machinery life by keeping oil clean, dry and fit for use.	▾ Detect damage early. ▾ Analyze metal particle from mechanical defects. ▾ Identify root cause and severity using WDA.

Figure 5. Vibration and Oil Analysis are Complementary Condition-Monitoring Technologies

Corrosive wear is driven by three primary factors: the presence of a corrosive media such as water, the length of time the metal surfaces are exposed to the corrosive fluid, and temperature. Corrosion, like other chemical processes, is accelerated by temperature. Concentration is also a factor - less is better and more is worse.

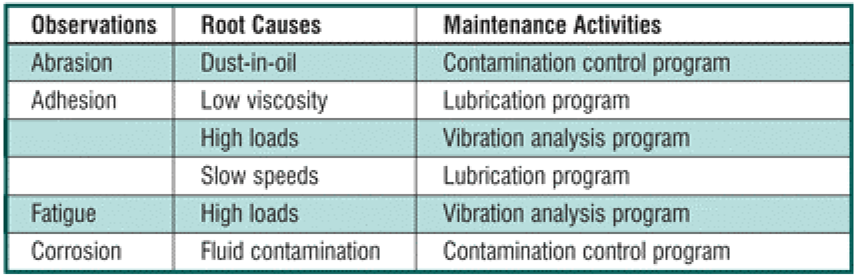
A practical approach to corrosive fluid contamination control is to set a threshold level, such as 0.1 percent (1000 ppm) water-in-oil. Any system found to be contaminated with water should be dehydrated and modified to exclude water if possible. When nearly all the critical lubrication systems have achieved this level, then move the bar down to 0.05 percent (500 ppm) and focus attention on the ones that cross this lower alarm.

Maintenance Priorities

Machinery health management is aimed at long machine life with reliable operation.

Abrasion, adhesion, fatigue and corrosion are actively wearing down load-bearing surfaces. Identifying and eliminating the root causes is accomplished by implementing three programs (contamination control, lubrication and vibration analysis) as outlined in Table 1.

Table 1



Observations	Root Causes	Maintenance Activities
Abrasion	Dust-in-oil	Contamination control program
Adhesion	Low viscosity	Lubrication program
	High loads	Vibration analysis program
	Slow speeds	Lubrication program
Fatigue	High loads	Vibration analysis program
Corrosion	Fluid contamination	Contamination control program

Maintenance priorities will naturally include other activities in addition to other condition-monitoring technologies (such as ultrasonics and infrared) that are beyond the scope of this article.

Vibration and Oil Analysis

Vibration and oil analysis are complementary, not redundant. Both technologies are proactive, revealing critical root causes that could cause damage if not corrected. These technologies are also predictive, and reveal information about failure in progress. They provide important insights about root cause and severity, and suggest appropriate corrective actions based on the particular results.

Reference

1. Bayer, Raymond. (2002). “Wear for Engineers.” HNB Publishing.

Editor’s Note

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