Practical Applications

Recognition and Solution of Some Common Wear Problems Related to Lubricants and Hydraulic Fluids

by Douglas Godfrey (Fellow, STLE)

Editor's Note: *This article was originally published as a compilation of articles from the series "Starting from Scratch: Tribology Basics," previously published in Lubrication Engineering (TLT's predecessor).*

INTRODUCTION

Kinds of Wear

The purpose of this article is to share my practical experience in solving eleven common wear problems related to lubricants and hydraulic fluids. The wear mechanisms to be discussed include:

- Mild Adhesion
- Severe Adhesion
- Abrasion
- Erosion
- Polishing
- Contact Fatigue
- Corrosion
- Fretting Corrosion
- Electro Corrosion
- Electrical Discharge
- Cavitation Damage

Some fundamental tribologists try to seek a few basic wear mechanisms, but those listed above are justified in my opinion because each has a different cause, different symptoms and different solutions. Knowledge of two or three underlying mechanisms such as cutting and corrosion would not help solve the problems.

There are other wear processes. In addition to those listed, Peterson has included impact, gouging, wire drawing, metal/metal, fluid erosion, rain erosion impingement, erosion-corrosion and deformation (1). Archard's list includes surface fracture, tearing and melting (2). In various publications, Quinn et. al. have written about oxidative wear. Delamination wear was not included because it is a metal removal mechanism that may be operative in mild or severe wear or abrasive wear depending upon conditions. It does explain flake-type wear fragments. Barwell describes gouging as intense plowing action with plastic deformation and cutting (3). Jahanmir included diffusive and impact wear in his list (4). The list of references on page 21 provides citations for further reading on selected topics.

INTERRELATIONSHIPS

Wear mechanisms do not usually occur alone but two or three may occur at the same time, or in sequence. For example, fretting corrosion and contact fatigue may occur together. The wear fragments from severe adhesion may subsequently cause abrasion. Hard particles in oil denting rolling element bearings, lead to contact fatigue. Rowe has described the required balance of minimum corrosion by additives to reduce adhesive wear (5), (6). In one paper the authors showed that abrasive in an oil can promote scuffing (7).

METHODS OF ANALYSIS

Details of diagnostic procedures and instruments are given in Refs. (8) and (9). However, examination of the surfaces by a hand lens, or better a stereo microscope, is the first and most important step. A scanning electron microscope is the most effective instrument in tribology. Analysis of wear products on the parts or in the oil is useful. Analytical methods include emission spectrometry, X-ray diffraction and ferrography. The appendix on this page describes two simple useful spot tests.

TABLE

The table on pages 22-23 lists the names and definitions of the wear mechanisms, their symptoms by various methods and some ideas on prevention. My definitions favor, but may modify, those developed by O.E.C.D. (10).

APPEARANCE OF WORN SUFACES

Manufacturers of equipment, especially journal and rolling element bearings provide bulletins showing photographs of worn parts. In the tribology literature there are numerous papers showing the appearance of worn parts (8), (11), (12), (13), (14) and (15).

APPENDIX

Copper Sulfate Test

A solution of cooper sulfate will detect metallic iron by forming a pink color. The copper in solution replaces iron electrochemically.

Make a saturated solution of copper sulfate in water slightly acidified with sulfuric acid. De-oil or degrease surfaces of which iron is suspected to be present. Add one or two drops of test solution. In about 30 seconds or less, pink (copper) coloration will appear where iron is present. The test is very useful for detecting scuffed chromium-plated piston rings run against cast iron or babbitt bearings run against a steel shaft.

Sulfide Print Test

This test, using photographic paper dampened with two percent sulfuric acid, detects iron sulfide films or wear fragments related to corrosive and polishing wear (16). The sulfuric acid converts iron sulfide to H_2S which in turn converts sliver in the emulsion to silver sulfide.

Obtain a few sheets of uncoated photographic paper and store in a light-proof box. Prepare a two-percent solution of sulfuric acid in water. In subdued light identify the emulsion or shiny side of the photographic paper by writing on the opposite (dull) side of the paper and then cut the paper up into useful pieces.

Soak the pieces of the photographic paper in the acid solution for two or three minutes, then damp dry on paper towels. Place the emulsion side of the paper against the de-oiled surface where iron sulfide is suspected. Hold for two minutes at room temperature without any sliding. Remove carefully, wash and treat the print with fixer and wash again and dry. Wash and dry the metal part to stop corrosion. The location and amount of iron sulfide will be indicated by the intensity of the resultant brown color. This test is weakly positive for zinc sulfide. **<<**

Douglas Godfrey heads his own consulting company, Wear Analysis in San Rafael, Calif. You can contact him at **douggodfr@aol.com**.

REFERENCES

(1) Peterson, M.B. (1980), "Classification of Wear Processes," *Wear Control Handbook*, ASME, New York, pp. 9-34.

(2) Archard, J.F. (1980), "Wear Theory and Mechanisms," *Wear Control Handbook*, ASME, New York, pp. 35-80.

(3) Barwell, F.T. (1979), "Bearing Systems — Principles and Practices," Oxford Press.

(4) Jahanmir, S, (1980), "On the Wear Mechanisms and the Wear Equations," *Fundamentals of Tribology*," Eds. Suh, N.P. and Saka, N., MIT Press, Cambridge, Mass., pp. 455-467.

(5) Rowe, C.N., "Lubricated Wear," *Wear Control Handbook*, ASME, New York, pp. 143-160.

(6) Rowe, C.N. (1984), "Lubricated Wear," *Handbook of Lubrication Vol*. II, Ed. Booser, E.R., CRC Press, Boca Raton, Fla., pp. 209-225.

(7) Chandrasekaran, S., Khemchandani, M.V. and Sharma, J.P. (1985), "Effect of Abrasive Contaminants on Scuffing," *Tribology Inter.* **18**, 4, pp. 219-222.

(8) Godfrey, D. (1980), "Diagnosis of Wear Mechanisms," *Wear Control Handbook*, ASME, New York, pp. 283-311.

(9) Godfrey, D. (1980), "Review of Usefulness of New Surface Analysis Instruments in Understanding Boundary Lubrication," *Fundamentals of Tribology*, Eds. Suh, N.P. and Saka, N., MIT Press, Cambridge, Mass., pp. 945-965.

(10) *Wear Control Handbook*, Eds. Peterson, M.B. and Winer, W.O., ASME, New York, Appendix pp. 1143-1201 (1980).

(11) Tallian, I., et.al. (1974), *Rolling Bearing Damage*, *A Morphological Analysis*, SKF Industries, Philadelphia, Pa.

(12) *Tribology Handbook*, Ed. Neale, M.J., Newnes-Buterworth, London (1973); Plain Bearing Failures, Section E2, Holligan, P.T.; Rolling Bearing Failures, Section E3, Crump, W.J.J., Gear Failures, Section E4, Watson, H.J., Failure of Friction Surfaces, Section E5, Newcomb, T.P. and Spurr, R.T.; Seal Failures, Section E6, Nau, B.S.; Mechanisms of Wear, Section F-6, Wright, K.H.R.

(13) Kaufman, H.N. and Walp, H.O. (1980), "Interpreting Service Damage in Rolling-Type Bearings," ASLE..

(14) Engle, L. and Klingele, H. (1981), *An Atlas of Metal Damage*, Wolfe Science Books, Munich, Germany, English translation by Mussray, S.

(15) *Source Book on Wear Control Technology*, Eds. Rigney, D.A. and Glaeser, W.A., ASM, Metals Park, Ohio (1978).

(16) Kehl, G.L. (1949), "Principles of Metallographic Laboratory Practice," 3rd Edition, McGraw Hill, New York, pp. 186-187.

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COMMON WEAR PROBLEMS RELATED TO

CONTINUED FROM PAGE 21

Names of Wear: Preferred	Names of Wear: Other	Definition	Susceptible Machine Parts	Conditions Promoting Wear
Mild Adhesion	Normal [a]	Generally, transference of material from one surface to another due to adhesion and subsequent loosening during relative motion Mild adhesion involves transfer and loosening of surface films only.	All	Moderate loads, speeds and temperatures Good, clean, dry lubricants Proper surface finish
Severe Adhesion	Scuffing Galling Scoring [b]	Cold welding of metal surfaces due to intimate metal to metal contact	Piston rings and cylinder barrels Valve train Rolling & sliding bearings Gears Cutting tools Metal seals Chains	High loads, speeds and/or temperatures Use of stainless steels or aluminum Insufficient lubricant Lack of antiscuff additives No break in Abrasive wear
Abrasion	Cutting Scratching "Wire wool" damage Gouging Scoring	Cutting and deformation of material by hard particles (3-body) or hard protuberances (2-body)	All surfaces in relative motion	Hard particles contaminating oil Insufficient metal hardness Hard metal with rough surface against soft metal
Erosion	Solid particles impact erosion	Cutting of materials by hard particles in a high velocity fluid impinging on a surface	Journal bearings near oil holes Valves Nozzles	High velocity gas or liquid containing solids impinging on a surface [g]
Polishing	Bore polishing	Continuous removal of surface films by very fine abrasives	Cylinder bores of diesel engines Gear teeth Valve lifters	Combination of corrosive liquid and fine abrasive in oil [h]
Contact Fatigue	Fatigue wear Frosting Surface fatigue Spalling	Metal removal by cracking and pitting, due to cyclic elastic stress during rolling and sliding	Rolling and sliding bearings Valve train parts Gears	Cyclic stress over long periods Water, dirt, in oil Inclusions in steel
Corrosion	Chemical wear Oxidative wear Corrosive film wear	Rubbing off of corrosion products on a surface	All bearings Cylinder walls Valve train Gears Seals and chains	Corrosive environment Corrodible metals Rust promoting conditions [j] High temperatures
Fretting Corrosion	False brinelling Fretting Friction oxidation	Wear between two solid surfaces experiencing oscillatory relative motion of low amplitude	Vibrating machines Bearing housing contacts Splines, keys, couplings Fasteners	Vibration causing relative motion
Electro-corrosion	"Erosion" Electrical erosion Electro chemical wear Electrical attack	Dissolution of a metal in an electrically conductive liquid by low amperage currents	Aircraft hydraulic valves Hydraulic pumps and motors	High velocity liquid flow causing streaming potentials Stray currents Galvanic metal combinations
Electrical Discharge	Electrical pitting Sparking	Removal of metal by high amperage electrical discharge or spark between two surfaces	Bearings in high speed rotating machinery such as, compressors, atomizers Static charge producers	High speed rotation High velocity two phase fluid mixtures High potential contacts Sparks
Cavitation Damage [m]	Cavitation erosion Fluid erosion	Removal of metal by bubble implosion in a cavitating liquid	Hydraulic parts, pumps valves, gear teeth Cylinder liners, piston rings Sliding bearings	Sudden changes in liquid pressure due to changes in liquid velocity or to shape or motion of parts [n]

a Mild adhesion is a desirable wear condition.
b Scoring is not recommended because it implies a scratch or furrow cut by abrasion.
c Emission spectroscopy usually misses large (>5 micron) wear fragments.
d Increasing metal hardness does not reduce scuffing.
e The most common wear problem.
f Do not shot peen, bead or sandblast any surface in a lubricated machine because abrasive cannot readily be removed completely.
g Sandblasting embeds sand in surfaces.
h An example of polishing combination in oil is active sulfur additive and Fe_2O_3 (jeweler's rouge).

Symptoms			Prevention	
Unaided Eye	Microscopically	Oil Analysis	Mechanical Changes	Lubricant Changes
Low rates of wear No damage Deeper original grinding marks still visible	Smooth micro plateaus among original grinding marks Slight coloration due to films	1-5ppm wear metals by emission spectroscopy Low % solids by filtration Metal salts (oxides, sulfides, phosphates, etc.) in wear fragments by X-ray diffraction.	None	None
Rough, torn, melted or plastically deformed metal, broad or streaks High temperature oxidation High friction, high rates of wear Possible seizure	Rough irregular surface Metal from one surface adhering to other surface by spot tests or microprobe analysis	Large metallic wear fragments of irregular shape [c]	Reduce load, speed and temperature Improve oil cooling Use compatible metals Apply surface coatings such as phosphating Modify surface, such as ion implantation [d]	Use more viscous oil to separate surfaces Use "extreme pressure" additives such as a sulfur-phosphorous or borate compounds
Scratches or parallel furrows in the direction of motion, similar to "sanding" High rates of wear	Clean furrows, burrs, chips Embedded abrasive particles In sliding bearings with soft overlay embedded particles cause polished rings	High metal content in oil and high silicon (>10ppm) by emission spectroscopy High % solids by filtration Chips and burrs by ferrography	Remove abrasive by improved air and oil filtering, clean oil handling practices, improved seals, flushing and frequent oil changes [f] Increase hardness of metal surfaces	Use oil free of abrasive particles Use more viscous oil
Smooth broad grooves in direction of fluid flow Matte texture, clean metal Similar to sandblasting	Short V-shaped furrows by scanning electron microscopy Embedded hard particles	Elements of hard particles by emission spectrograph Chips and burrs by ferrography	(same as above) Reduce impact angle to less than 15°	(same as above)
High wear but a bright mirror finish Wavy profile	Featureless surface except scratches at high magnification by by electron microscopy	Combination of fine metal corrosion products and fine abrasive by X-ray diffraction	None	Choose less chemically active additive Remove corrosive contaminant Remove abrasive
Cracks, pits and spalls	Combination of cracks and pits with sharp edges Subsurface cracks by metallographic cross section. Numerous metal inclusions	Particles of metal with sharp edges Metal spheres by electron microscopy	Reduce contact pressures and frequency of cyclic stress Use high quality vacuum melted steels Use less abusive surface finish	Use clean, dry oil Use more viscous oil Use oil with higher pressure viscosity coefficient [i]
Corroded metal surface	Scale, films, pits containing corrosion products Dissolution of one phase in a 2-phase alloy	Detection of corrosion products of worn metal Detection of anion, such as chlorine by X-ray fluorescence	Use more corrosion resistant metal (not stainless) Reduce operating temperature Eliminate corrosive material	Remove corrosive material such as too chemically active additive & contaminates Use improved corrosion inhibitor Use fresh oil
Corroded stained surfaces [k] Loose colored debris around real contact areas Rouge (Fe_2O_3) colored films, debris, grease or oil for steel	Thick films of oxide of metal. Red and black for steel	Identify metal oxide ($\propto Fe_2O_3$ for steel) by X-ray diffraction	Reduce or stop vibration by tighter fit or higher load. Improve lubrication between surfaces by rougher (then honed) surface finish	Use oil of lower viscosity Relubricate frequently Use oxidation inhibitors in oil
Local corroded areas Black spots such as made by a small drop of acid Corroded, worn metering edges	Corrosion pits, films dissolution of metals	Detection of corrosion products Electrically conductive liquids [l]	Decrease liquid velocity and velocity gradients Use corrosion-resistant metals Eliminate stray currents Use nongalvanic couples	Decrease or increase electrical conductivity of lubricants or hydraulic fluids
Metal surface appears etched. In thrust bearings sparks make tracks like an electrical engraver	Pits, near edge of damage, showing once molten state, such as smooth bottoms, rounded particles, gas holes Rounded particles near pits welded to surface	Detection of large rounded particles by microscopic examination of filtrate or in ferrograph	Improve electrical insulation of bearings Degauss magnetic rotating parts Install brushes on shaft Improve machine grounding	Use of oil of higher electrical conductivity
Clean frosted or rough appearing metal Deep rough pits or grooves	Clean, metallic bright rough metal, pits Removal of softer phase from two-phase metal [o]	Observation of large chunks or spheres of metals in oils	Use hard tough metals such as tool steel Reduce vibration, flow velocities and pressures Avoid restriction and obstructions to liquid flow	Avoid low vapor pressure, aerated, wet oils Use noncorrosive oils

i A new additive reduces promotion of contact fatigue by water; some extreme pressure additives are suspected of promoting contact fatigue.

j Rust (hydrated iron oxide $Fe_2O_3H_2O$) is common corrosion product of ferrous metal.

k Damage on one surface is mirror image of damage on other.

i Highly compounded oils can be electrically conductive — or electrolytes; phosphate ester hydraulic fluids are conductive.

m Not to be confused with pump cavitation which is a different phenomenon.

n Corrosion and abrasive in oil increase cavitation damage.

o Graphite phase in cast iron susceptible to removal by cavitation.