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Research Paper

MICROSTRUCTURAL ANALYSIS OF WEAR DEBRIS

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Wear generates debris. The debris comes in a wide variety of sizes and shapes. Wear debris turns motor oil black. The black in used oil is like a pigment, it is nanometer-size colloidal metal particles (and carbon) suspended in the oil.Wear debris represents loss of geometric accuracy of moving contacting parts. It can also foul orificesand close spaced parts. Although the total material lost as wear debris in a machine is minute comparedto the volume and weight of the moving parts, it can signal failure of gears or bearings, and expensiverepairs or warranty payments.Until the Industrial Revolution and the development of steam and internal combustion engines, wear was taken for granted. When wear of machinery and tools became a problem, the development of wearresistantmaterials and the study of wear itself increased rapidly. Now we have a large body of informationdeveloped from experience and scientific investigation that can be used in the design and maintenanceof more reliable and economical machinery.

Keywords: Wear debris, Spectrographic oil analysis

INTRODUCTION

Early Wear Theory as related by Bowdon and Tabor(1964) and Holm (1946) indicated that real surface contact at high spots in the surface micro topography (asperities) and wear was caused by shearing off these contacts. The theory was not clear, however, on how the wear particles were separated from contacting asperities. Under abrasive wear conditions, it is presumed that hard particles embedded in one surface will plow through a softer counter face and produce micro chips. The debris thus generated looks like as shown in the given Figure 1.

In general, the higher the hardness of a metal the more susceptible to cutting wear it is. Contact load between sliding surface does not have to be large for cutting wear to take place. Wear debris can also be generated by plastic deformation.Hard asperities, plowing over a softer surface without cutting will produce ridges. Ridges can then be flattened by further contact. Extrusions or lips are formed. These lips are broken off and become flat wear flakes. Another method for generating wear debris includes material transfer from one surface to another. An asperity plowing through a surface will cold

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weld to the mating surface and the weld will shear off, leaving some of theasperity stuck to the mating surface. Anin situscanning electron microscope (SEM) wear experiment by Glaeser (1981) demonstrated this process.

Figure 1: SEM Micrograph of Cutting-type Debris from Abrasive Wear

In circulating oil systems, the SOAP (spectrographic oil analysis program) process of debris monitoring has proved valuable in certain applications. Instead of extracting the debris from the oil, the whole oil sample is subjected to spectrographic analysis.

The following potential failures can be detected in this way:

- Broken piston rings, worn or scuffed cylinder walls, and worn valve guides
- Worn ball or roller bearings and/or retainers
- Worn journal bearings
- Worn spline couplings
- Worn cams and followers
- Scored pistons in hydraulic pumps

Wear debris can be collected by allowing it to fall on a glass slide. The debris can then be fixed to the slide and examined under a microscope. In a circulating oil system, a filter in the line can be used to collect debris. Debris can be washed out of the filter with solvent, or the filter element, if of an organic material, can be dissolved by an appropriate solvent and the remaining metallic debris collected.It must be assumed that debris collected from a wear process is as it was when separated from a surface if one is to deduce how it was generated. This often is not the case. Wear debris can go through a contact zone many times and in the process be altered in size and shape. This is true in roller bearings, reciprocating flat-on-flat sliders, splines, gear couplings, and wet clutches. Ductile metals can be mashed out into extremely thin flakes - thin enough to transmit electrons. When these submicron particles are examined in a transmitting electron microscope (TEM), they appear transparent.

Figure 2: TEM Micrograph of a Submicron Wear Particle Embedded in a Gel

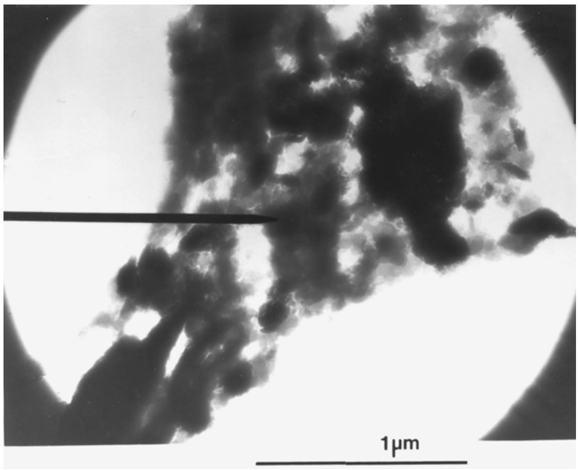
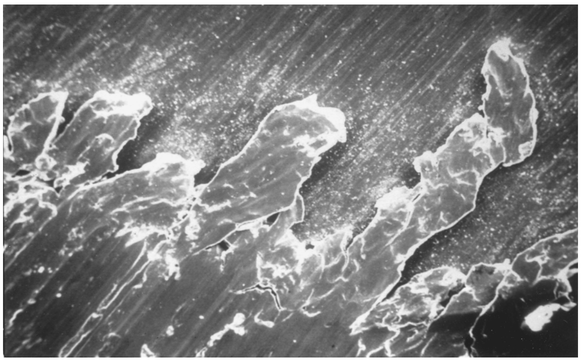


Figure 3: SEM Micrograph of Stainless Steel Extrusions



EXPERIMENTAL PROCEDURE

Most of the wear debris formed by the above mechanisms is visible using light microscopy. Submicron debris can be found in SEM analysis of material filtered from used oil. In a series of experiments designedto observe the generation of wear debris under lubricated conditions, a block-on-ring wear tester was used by Glaeser (1983). The block was Cu-3.2 wt% Al alloy and the ring was carburized steel. A drop of silicone oil was applied to the ring so that it clung to the bottom of the ring.The drop was illuminated with a light source and was observed through a microscope. As the ring rotated, oil from the drop circulated through the block contact and back to the drop, carrying any debris generated into the drop. At the beginning of rotation, the oil drop began to fill with metal flakes that sparkled as they tumbled in the drop. Later in the test, the drop became cloudy. At this point,the experiment was terminated and the drop removed for analysis. The large wear debris was removedby centrifuging. The still cloudy oil was then filtered through a Nucleopore polycarbonate filter. The filter was mounted on a carbon grid for an electron microscope and the filter dissolved with a solvent. The remaining material was then examined in a transmission electron microscope and was found to consist of equiaxed nano particles embedded in a gel.EDX analysis of the particle showed it to be 80% Cu, 1.6% Fe, and 2% Al. The balance was silicon. Thesilicone oil had formed a gel with the submicron metal particles. The large bronze flakes that appearedinitially were from the wear-in process as the roughness in the bronze surface was removed. Heavy surface flow produced smeared layers. As these layers were subjected to increasing numbers of rubbing cycles,particles broke off and were trapped in the surface. These particles were reduced to very small particles by comminution, as happens in the ball milling process.

SEM analysis revealed particle reduction in progress on the aluminum bronze block . The submicron particles produced reacted with the oxidizing lubricant to form a gel which clouded the oil drop. This type of wear is often found in boundary-lubricated or very thin film elasto hydrodynamic-lubricated contacting surfaces.

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RESULTS AND DISCUSSION

Wear debris comes in all sizes and shapes. The way in which the debris has been formed can be deduced from size, shape, and surface texture. For instance, cutting wear debris is unique in having a curly and stringy shape. The presence of cutting wear debris in an oil sample signals a severe wear problem needing immediate attention.

Figure 4: Spherical Wear Debris From Grinding Swarf

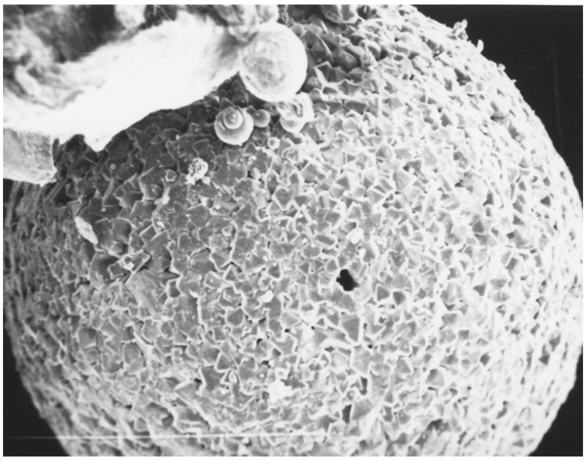
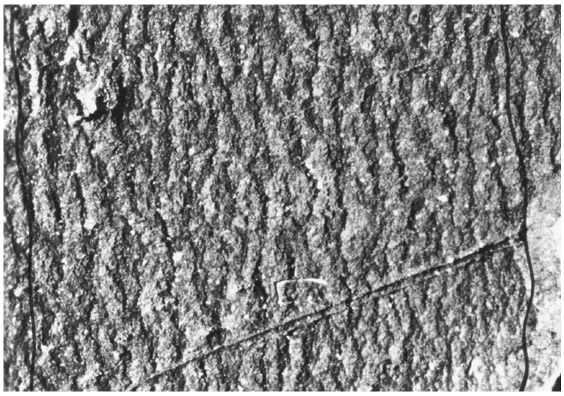


Figure 5: Rubber Abrasion Pattern



Use of wear debris as a diagnostic tool for the health of operating machinery is difficult. Recognition of significant morphological characteristics, color, and chemical make up of the variety of particles and elements that turn up in a sample requires experience. The SOAP program has proven effective for truck, tank, and railroad diesels, hydraulic systems, gear boxes, and compressors. The diagnosis is based on the history of concentration of specific elements found in oil samples. The particles involved are under 10 μm in size and more likely to be of submicron size. They are detected by spectrographic methods which give quantitative results, usually in ppm. The trends for several metals are compared with the original oil sample taken at hour one. By experience, these trends (for instance, sudden continuing increase in iron content) can be related to pending wear failures of certain components.

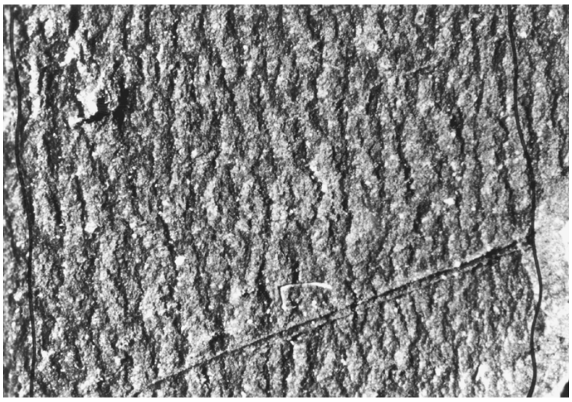
Particles from a given sample of oil separated by ferrograph or other methods can be classified as to size and a size-frequency distribution plot made. Assuming that the larger particles are related to severe wear, significant increases in their content compared with the running-in plot should signal shut down and maintenance.

Some of the more easily recognized characteristics of wear particles include:

- Wear-in conditions. Flat, fairly smooth particles about 10 ?m or smaller formed from broken off lips and extrusions produced by machining.
- Cutting. Curled strings and crumpled flakes resulting from abrasive wear process.
- Deformation. Flat flakes with parallel striations from breakout of deformed surface material caused by heavy sliding contact.

It must be assumed that debris collected from a wear process is as it was when separated from a surface if one is to deduce how it was generated. This often is not the case. Wear debris can go through a contact zone many times and in the process be altered in size and shape. This is true in roller bearings, reciprocating flat-on-flat sliders, splines, gear couplings, and wet clutches. Ductile metals can be mashed out into extremely thin flakes - thin enough to transmit electrons. When these submicron particles are examined in a transmitting electron microscope (TEM), they appear transparent.

Figure 6: TEM Micrograph of an Iron Particle Subjected to Ball Milling to Simulate Wear Debris Subject to Tepeated Passage Through a Rolling Contract



Under heavy load, surface features can be produced that are peculiar to the surface morphology. The surface of an Al-Si alloy pin which had been run against a hardened disk had developed “inclined shear plates” on the surface. A particle, extracted from the wear debris showed the same morphology. Therefore, it was recognized as a piece of the pin surface broken out during heavy sliding contact. Ferrographs will also collect nonmagnetic and nonmetallic particles. They will tend to precipitate out of the fluid as it moves over the glass slide. The same analysis can be performed on wear particles separated from oil by other means (filters, centrifuging). Organic materials can be detected by viewing the slide with transmitted light. Polarized light will show up crystalline minerals.

CONCLUSION

Wear debris comes in many sizes and shapes. Study of wear debris morphology and chemistry can provide clues to the condition of various lubricated parts in a machine and the wear mechanisms extent, allthis without tearing an engine down. By monitoring the amounts of given metals in a circulating oil system as a function of running time, one can detect the onset of a mechanical part (bearing, gear, piston ring, or seal) failure. This program (SOAP) has been successfully used for a number of years for conditionmonitoring of engines.Individual wear particles can provide clues to the wear mechanism that produced them. For instance,a sudden increase in bronze particles from an engine with bronze bearings may be the result of ingestionof abrasive contaminants. Just monitoring the increase in copper in the oil would not indicate the changein wear mode. Bronze particle size and shape would suggest this. Failure analyses can be enhanced bythe examination of wear particle size and shape.

Researchers can use wear particle analysis as a tool to follow the wear process as it changes with changesin operating conditions (bearing load, change in environment, increased sliding velocity). Classificationof wear debris according to size, thickness, shape, color, and chemistry and relating debris types to wearmechanisms or failure of mechanical components has been the goal of debris atlases. However, care mustbe exercised in using this information since the character of wear debris is often influenced by factorsother than wear mode or parts failure. Diagnostics with wear debris requires experience in interpreting and recognizing significant characteristics.

ACKNOWLEDGMENT

I would also like to dedicate this research work to my father Late R S Mishra and mother KL Mishra.

REFERENCES

1. Anderson D P (1982), “Wear Particle Atlas”, *NAEC Report 92-163, Lakehurst, NJ*.
2. Bowen E R, Scott D, Seifert W W and Westcott V C (1964), “Ferrography”, *Tribology International*.
3. Bowden F P and Tabor D (1964), “The Friction and Lubrication of Solids”, *Part 1 (1950) and Part II, Oxford Press, London*.
4. Davies J E (1986), “Spherical Debris in Engine Oil”, *Wear*.
5. Glaeser W A (1981), “Wear Experiments in the Scanning Electron Microscope”, *Wear*.
6. Glaeser W A (1991), “Ball Mill Simulation of Wear Debris Attrition”, *Proceedings, 18th Leeds-Lyon Symposiumon Tribology, Tribology Series 21, Elsevier*.
7. Holm R (1946), “Electric Contacts, Almquist and Wicksells”, *Uppsala, Sweden*.