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Standard Guide for Microscopic Characterization of Particles from In-Service Lubricants[1]

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1. Scope

1.1 This guide covers the classification and reporting of results from in-service lubricant particulate debris analysis obtained by microscopic inspection of wear and contaminant particles extracted from in-service lubricant and hydraulic oil samples. This guide suggests standardized terminology to promote consistent reporting, provides logical framework to document likely or possible root causes, and supports inference associated machinery health condition or severity based on available debris analysis information.

1.2 This guide shall be used in conjunction with an appropriate wear debris analysis sample preparation and inspection technique including, but not limited to, one of the following:

1.2.1 Ferrography using linear glass slides,

1.2.2 Ferrography using rotary glass slides,

1.2.3 Patch analysis using patch makers (filtration through membrane filters),

1.2.4 Filter debris analysis,

1.2.5 Magnetic plug inspection, or

1.2.6 Other means used to extract and inspect particulate debris from in-service lubricants.

1.3 This standard is not intended to evaluate or characterize the advantage or disadvantage of one or another of these particular particle extraction and inspection methods.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D4130 Test Method for Sulfate Ion in Brackish Water, Seawater, and Brines

D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants

D7416 Practice for Analysis of In-Service Lubricants Using a Particular Five-Part (Dielectric Permittivity, Time-Resolved Dielectric Permittivity with Switching Magnetic Fields, Laser Particle Counter, Microscopic Debris Analysis, and Orbital Viscometer) Integrated Tester

D7596 Test Method for Automatic Particle Counting and Particle Shape Classification of Oils Using a Direct Imaging Integrated Tester

D7647 Test Method for Automatic Particle Counting of Lubricating and Hydraulic Fluids Using Dilution Techniques to Eliminate the Contribution of Water and Interfering Soft Particles by Light Extinction

D7690 Practice for Microscopic Characterization of Particles from In-Service Lubricants by Analytical Ferrography

G40 Terminology Relating to Wear and Erosion

2.2 *ISO Standard:*[3]

ISO 11171 Hydraulic fluid power – Calibration of automatic particle counters for liquids

3. Terminology

3.1 *Definitions:*

3.1.1 *abrasive wear, n*—wear due to hard particles or hard protuberances forced against and moving along a solid surface. **G40**

[1] This guide is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.96.06 on Practices and Techniques for Prediction and Determination of Microscopic Wear and Wear-related Properties.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.

3.1.2 *abrasion, n*—wear by displacement of material caused by hard particles or hard protuberances. **D4175**

3.1.3 *break-in, n*—see *run-in*. **G40**

3.1.4 *fatigue wear, n*—wear of a solid surface caused by fracture arising from material fatigue. **G40**

3.1.5 *fretting, n—in tribology*, small amplitude oscillatory motion, usually tangential, between two solid surfaces in contact.

3.1.5.1 *Discussion*—Here the term fretting refers only to the nature of the motion without reference to the wear, corrosion, or other damage that may ensue. The term fretting is often used to denote fretting corrosion and other forms of fretting wear. Usage in this sense is discouraged due to the ambiguity that may arise. **G40**

3.1.6 *fretting wear, n*—wear arising as a result of fretting (see *fretting*). **G40**

3.1.7 *lubricant, n*—any material interposed between two surfaces that reduces the friction or wear between them. **D4175**

3.1.8 *lubricating oil, n*—liquid lubricant, usually comprising several ingredients, including a major portion of base oil and minor portions of various additives. **D4175**

3.1.9 *rolling, v*—motion in a direction parallel to the plane of a revolute body (ball, cylinder, wheel, and so forth) on a surface without relative slip between the surfaces in all or part of the contact area. **G40**

3.1.10 *rolling contact fatigue, n*—damage process in a triboelement subjected to repeated rolling contact loads, involving the initiation and propagation of fatigue cracks in or under the contact surface, eventually culminating in surface pits or spalls. **G40**

3.1.11 *run-in, n—in tribology*, an initial transition process occurring in newly established wearing contacts, often accompanied by transients in coefficient of friction or wear rate, or both, that are uncharacteristic of the given tribological system's behavior. Syn. *break-in* and *wear-in*. **G40**

3.1.12 *rust, n—of ferrous alloys*, a corrosion product consisting primarily of hydrated iron oxides. **D4175**

3.1.13 *sliding wear, n*—wear due to the relative motion in the tangential plane of contact between two solid bodies. **G40**

3.1.14 *sludge, n*—precipitate or sediment from oxidized mineral oil and water. **D4130**

3.1.15 *spalling, n—in tribology*, the separation of macroscopic particles from a surface in the form of flakes or chips, usually associated with rolling element bearings and gear teeth, but also resulting from impact events. **G40**

3.1.16 *three-body abrasive wear, n*—form of abrasive wear in which wear is produced by loose particles introduced or generated between the contacting surfaces.

3.1.16.1 *Discussion*—In tribology, loose particles are considered to be a "third body." **G40**

3.1.17 *two-body abrasive wear, n*—form of abrasive wear in which the hard particles or protuberances that produce the wear of one body are fixed on the surface of the opposing body. **G40**

3.1.18 *wear, n*—damage to a solid surface, usually involving progressive loss or displacement of material, due to relative motion between that surface and a contacting substance or substances. **D4175, G40**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *abrasive wear particles, n*—long wire-like particles in the form of loops or spirals that are generated due to hard, abrasive particles present between wearing surfaces of unequal hardness; sometimes called *cutting wear particles* or *ribbons*.

3.2.2 *analytical ferrography, n*—technique whereby particles from an oil sample deposited by a ferrograph are identified to aid in establishing wear mode inside an oil-wetted path of a machine.

3.2.3 *chunks, n*—free metal particles >5 µm with a shape factor (major dimension to thickness ratio) of <5:1.

3.2.4 *contaminant particles, n*—particles introduced from an extraneous source into the lubricant of a machine or engine.

3.2.5 *corrosive wear debris, n*—usually, extremely fine partially oxidized particles caused by corrosive attack. Particles can become quite large in cases of extreme corrosion.

3.2.6 *debris, n—in tribology*, solid or semi-solid particulate matter introduced to lubricant through contamination or detached from a surface due to a wear, corrosion, or erosion process.

3.2.7 *ferrograph, n*—apparatus that magnetically separates and deposits wear and contaminant particles onto a specially prepared glass microscope slide.

3.2.8 *fibers, n*—long, thin, nonmetallic particles.

3.2.9 *filter debris analysis, n—in tribology*, a process for extracting and inspecting debris accumulated on the filter media taken from an in-line circulating lubrication system.

3.2.10 *filter patch analysis, n—in tribology*, a process using a filter patch maker to extract solid or semi-solid matter from a liquid and subsequently analyzing the extracted solid or semi-solid matter.

3.2.11 *filter patch maker, n—in tribology*, apparatus to extract solid or semi-solid matter from liquid by drawing a volume of solid-containing-liquid through a filter patch having pores of prescribed dimension sufficient to retain the solid or semi-solid matter while allowing the liquid to pass through.

3.2.12 *normal, n—in a five level severity ranking*, a one-of-five relative severity rating commonly associated with undamaged or as-new condition having reasonable wear or expected operational condition; see also *low alert*, *high alert*, *low fault*, and *high fault severity conditions*.

3.2.13 *low alert, n—in a five level severity ranking*, a two-of-five level relative severity commonly associated with some deterioration from normal condition, however intervention is not yet recommended; see also *normal*, *high alert*, *low fault*, and *high fault severity ranking*.

3.2.14 *high alert, n—in a five level severity ranking*, a three-of-five level relative severity commonly associated with significant deterioration from normal condition closely approaching need for intervention; see also *normal*, *low alert*, *low fault*, and *high fault severity ranking*.

3.2.15 *low fault, n—in a five level severity ranking*, a four-of-five relative severity commonly associated with significant deterioration from alert condition, and intervention is recommended now; see also *normal*, *low alert*, *high alert*, and*high fault severity ranking*.

3.2.16 *high fault, n—in a five level severity ranking*, a five-of-five relative severity commonly associated with significant deterioration from alert condition, and intervention is both recommended and overdue; see also *normal*, *low alert*, *high alert*, and *low fault severity ranking*.

3.2.17 *magnetic plug inspection*—process for inspecting and, if necessary, extracting ferrous alloy debris from in-service lubricants using a magnetic object placed in the oil compartment, typically associated with a drain plug.

3.2.18 *nonmetallic particles, n—in tribology*, particles comprised of compounds, organic material, sand, dirt, glasses, and so forth, that often demonstrate some element of translucence under microscopic backlight.

3.2.19 *platelets, n*—flat metal particles with a length more-or-less equal to their width, and a major dimension-to-thickness ratio in the range of approximately 5:1 to 10:1 or more (see *rolling contact fatigue particles*).

3.2.20 *red oxide particles, n*—rust particles present as polycrystalline agglomerates of Fe_2O_3 appearing orange in reflected white light. These are usually due to water in the lubricating system.

3.2.21 *reworked particles, n*—large, very thin, free metal particles often in the range of 20 to 50 µm in major dimension with the frequent occurrence of holes consistent with the explanation that these are formed by the passage of a wear particle through a rolling contact.

3.2.22 *ribbons, n*—see *abrasive wear particles*.

3.2.23 *rolling contact fatigue particles, n*—flat platelets, with a length more-or-less equal to their width, with smooth surfaces, random, jagged and irregularly shaped circumferences, and a major dimension-to-thickness ratio in the range of approximately 5:1 to 10:1 or more.

3.2.24 *rolling contact fatigue wear, n—in tribology*, fatigue wear caused by loaded rolling contact typically between roller and race in bearings or between gear teeth in the vicinity of the pitch line, typically forming spall-type pitting and releasing rolling contact fatigue particles (see 3.2.23); also called *rolling fatigue wear* or *subsurface spalling*.

3.2.25 *rubbing wear particles, n*—particles generated as a result of sliding wear in a machine, sometimes called mild adhesive wear. Rubbing wear particles are free metal platelets with smooth surfaces, from approximately 0.5 to 15 µm in major dimension and with major dimension-to-thickness ratios from about 10:1 for larger particles to about 3:1 for smaller particles. Any free metal particle <5 µm is classified as a rubbing wear particle regardless of shape factor unless it is a sphere.

3.2.26 *scoring, n—in tribology*, a consequence of severe sliding wear characterized by formation of extensive grooves and scratches in the direction of sliding; also called *striation*.

3.2.27 *severe sliding wear, n—in tribology*, sliding wear that removes subsurface metal; also called *abnormal sliding wear*.

3.2.28 *severe sliding wear particles, n—in tribology*, severe sliding wear particles are >15 µm and several times longer than they are wide. Some of these particles have surface striations as a result of sliding and they frequently have straight edges. Their major dimension-to-thickness ratio is approximately 10:1.

3.2.29 *severe wear particles, n—in tribology*, free metal particles >15 µm with major dimension-to-thickness ratios between 5:1 and 30:1.

3.2.30 *spheres, n—in tribology*, metal spheres may be the result of incipient rolling contact fatigue or they may be contaminant particles from welding, grinding, coal burning, and steel manufacturing. Spheres may also be caused by electro-pitting.

3.2.31 *wear particles, n*—particles generated from a wearing surface of a machine.

4. Summary of Guide

4.1 Periodic in-service lubricant samples are collected from a machine as part of a routine condition monitoring program. The sample is prepared to separate particles from the sample fluid. The separated particles are subsequently examined using an optical microscope to identify the types of particles present to aid in identifying the wear mode occurring in the oil-wetted path of the machine.

4.2 In usual practice of a routine condition monitoring program, particle separation and examination is not done for every sample taken, but may be done when routine tests such as spectrometric analysis, particle counting, or ferrous debris monitoring indicate abnormal results.

4.3 This guide is to be used with a sample preparation method that extracts particulate debris from in-service lubricant systems for subsequent microscopic examination.

4.4 The user of this guide should employ consistent terminology to achieve accepted and understandable interpretations when communicating instructions and findings based on particle analysis.

4.5 A process is suggested in standardized format to identify and further classify multiple distinct groups of particulate debris extracted from an in-service machinery lubricating sample.

4.6 A grid format is suggested in which the user of this guide can present findings and report possible root causes along with an assessment of associated machinery health condition or severity based on available debris analysis information.

4.7 An alternate classification scheme is suggested that is consistent with Practice D7690.

5. Significance and Use

5.1 The objective of particle examination is to diagnose the operational condition of the machine sampled based on the quantity and type of particles observed in the oil. After break-in, normally running machines exhibit consistent particle concentration and particle types from sample to sample. An increase in particle concentration, accompanied by an increase in size and severity of particle types, is indicative of initiation of a fault. This guide describes commonly found particles in in-service lubricants, but does not address methodology for quantification of particle concentration.

5.2 This guide is provided to promote improved and expanded use of particulate debris analysis with in-service lubricant analysis. It helps overcome some perceived complexity and resulting intimidation that effectively limits particulate debris analysis to the hands of a specialized and very limited number of practitioners. Standardized terminology and common reporting formats provide consistent interpretation and general understanding.

5.3 Without particulate debris analysis, in-service lubricant analysis results often fall short of concluding likely root cause or potential severity from analytical results because of missing information about the possible identification or extent of damaging mechanisms.

5.4 Caution shall be exercised when drawing conclusions from the particles found in a particular sample, especially if the sample being examined is the first from that type of machine. Some machines, during normal operation, generate wear particles that would be considered highly abnormal in other machines. For example, many gear boxes generate severe wear particles throughout their expected service life, whereas just a few severe wear particles from an aircraft gas turbine oil sample may be highly abnormal. Sound diagnostics require that a baseline, or typical wear particle signature, be established for each machine type under surveillance.

6. Reagents

6.1 Use reagents of type and purity following specifications from the manufacturer of the wear debris analysis sample preparation apparatus. Use reagents and solvents that do not contribute significant particles to the sample.

7. Procedure

7.1 Particulate matter extracted from in-service lubricants are displayed on a relatively flat surface such as a filter patch, glass slide, or other substrate for microscopic inspection. The procedure normally involves the following steps. These steps may be performed in this order or in a different order, and steps may be added as needed. This guide applies to interpreting microscopic observations (7.1.6) and reporting results (7.1.7) but does not address steps 7.1.1 – 7.1.5.

7.1.1 Collecting or concentrating particulate matter,

7.1.2 Depositing it on a surface to produce a specimen suitable for placement on an optical microscope stage,

7.1.3 Removing residual in-service lubricant fluid from the specimen,

7.1.4 Transporting the specimen to a microscope stage,

7.1.5 Using the microscope to inspect the specimen,

7.1.6 Interpreting observations, and

7.1.7 Recording results.

7.2 Use a desired particulate extraction technique to prepare a specimen for microscopic wear debris analysis. Specimens are prepared using an apparatus that effectively extracts solid particles from liquid samples and deposits the particles on a relatively flat supporting surface that can be placed on the viewing stage of an optical microscope.

7.3 Prepare specimens using one of the following particle extraction techniques:

7.3.1 Analytical ferrography using ferrograph to produce linear glass slides in accordance with Practice D7690,

7.3.2 Analytical ferrography using ferrograph to produced rotary glass slides,

7.3.3 Filter patch analysis using filter patch makers,

7.3.4 Filter debris analysis,

7.3.5 Magnetic plug inspection, or

7.3.6 Other means used to extract and inspect particulate debris from in-service lubricants.

7.4 Inspect the specimen using an optical microscope and classify particles using the following procedures. It is common for a single specimen to carry multiple kinds of particles so classification is normally done for a group of particles by characterizing individual particles representative of that group.

7.5 Therefore, the first step when inspecting a specimen normally involves scanning the entire specimen to identify particle types that are of interest by group. Next, each group is characterized in a logical sequence. An atlas of example images is typically used to provide consistency and to assist with cross-training between operators. One such atlas is described in the *Wear Particle Atlas*.[4]

7.6 For each group of particles the user should apply consistent characterization criteria. Two example approaches are given below in 7.7 and 7.8 that outline processes and format for analyzing and recording wear debris analysis classification findings.

7.7 For the first example of a particle classification approach, see Table 1, which shows a tabular grid a user may construct to guide inspection and documentation of wear debris analysis findings from a specimen. This kind of tabular grid may be printed out for note taking or it may be set up as a computerized form that an operator can click, check, or mark for ease of recording and database entry. An advantage of computerized record keeping using this sort of particle characterization is that a body of knowledge may be used together with this standardized terminology to support computerized expert system interpretation, review, and checking of data and results. This tabular grid (see Table 1) is typically used together with an image atlas including previously analyzed samples, particularly to assist new users to follow this logical thought and documentation sequence. Sections 7.7.1 – 7.7.11 describe the eleven columns found in Table 1.

7.7.1 Choose a sequence number to represent a particular group of particles observed for this specimen. Choose one

[4] Anderson, D. P., *Wear Particle Atlas (Revised)*, prepared for the Naval Air Engineering Center, Lakehurst, NJ 08733, 28 June 1982, Report NAEC-92-163. (Approved for public release; distribution unlimited.)

TABLE 1 Suggested Grid for Analysis and Classification of Particles

NOTE 1—Choose one item from each column for each particle group.

1	2	3	4	5	6	7	8	9	10	11
Group	Concentration	Size, average	Size, max	Aspect	Shape	Color	Texture	Composition	Classification	Severity
1	Few	Fine, <6 µm	Fine, <6 µm	1:1	Platelets	Red	Bright or Reflective	Ferrous Metal	Abrasive Wear	Normal
2	Moderate	Small, 6 to 14 µm	Small, 6 to 14 µm	1:2	Ribbons	Black	Dull or Oxidized	Cupric Metal	Mild Sliding Wear	Low Alert
3	Many	Medium, 14 to 40 µm	Medium, 14 to 40 µm	1:3	Chunks	Tempered	Pitted	Other Metal	Severe Sliding Wear (Metal Removal)	High Alert
4	Dense	Large, 40 to 100 µm	Large, 40 to 100 µm	1:10	Spheres	Metallic	Striated	Dust	Rolling Fatigue Wear (Subsurface Spall)	Low Fault
5		Huge, >100 µm	Huge, >100 µm	1:100	Spiral	Straw	Smeared	Organic	Corrosive Wear	High Fault
					Thermal	Copper	Amorphous	Sludge	Other Wear	
					Needles	Brass	Other texture	Paint Chips	Lube Degradation	
					Fibrous	Other Color		Other Material	Dust Contamina-tion	
					Powder				Other Contamina-tion	
					Other Shape					