Designation: D7690 – 11

Standard Practice for
Microscopic Characterization of Particles from In-Service Lubricants by Analytical Ferrography[1]

1. Scope

1.1 This practice covers the identification by optical microscopy of wear and contaminant particles commonly found in used lubricant and hydraulic oil samples that have been deposited on ferrograms. This practice relates to the identification of particles, but not to methods of determining particle concentration.

1.2 This practice interfaces with but generally excludes particles generated in the absence of lubrication, such as may be generated by erosion, impaction, gouging, or polishing.

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

1.4 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D4057 Practice for Manual Sampling of Petroleum and Petroleum Products

D4175 Terminology Relating to Petroleum, Petroleum Products, and Lubricants

D7684 Guide for Microscopic Characterization of Particles from In-Service Lubricants

G40 Terminology Relating to Wear and Erosion

3. Terminology

3.1 *Definitions:*

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

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

3.1.3 *adhesive wear, n*—wear due to localized bonding between contacting solid surfaces leading to material transfer between the two surfaces or loss from either surface. **G40**

3.1.4 *break-in, n*—See *run-in*. **D4175, G40**

3.1.5 *break in, v*—See *run in*. **G40**

3.1.6 *catastrophic wear, n*—rapidly occurring or accelerating surface damage, deterioration, or change of shape caused by wear to such a degree that the service life of a part is appreciably shortened or its function is destroyed. **G40**

3.1.7 *corrosion, n*—chemical or electrochemical reaction between a material, usually a metal surface, and its environment that can produce a deterioration of the material and its properties. **D4175**

3.1.8 *corrosive wear, n*—wear in which chemical or electrochemical reaction with the environment is significant. **G40**

3.1.9 *debris, n*—*in tribology*, particles that have become detached in a wear or erosion process. **G40**

3.1.10 *debris, n*—*in internal combustion engines,* solid contaminant materials unintentionally introduced in to the engine or resulting from wear. **D4175**

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

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

3.1.12.1 *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**

3.1.13 *fretting wear, n*—wear arising as a result of fretting. (See *fretting*.) **G40**

3.1.14 *friction, n*—resistance to sliding exhibited by two surfaces in contact with each other. Basically there are two frictional properties exhibited by any surface; static friction and kinetic friction. **D4175**

3.1.15 *impact wear, n*—wear due to collisions between two solid bodies where some component of the motion is perpendicular to the tangential plane of contact. **G40**

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

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

3.1.18 *pitting, n—in tribology*, form of wear characterized by the presence of surface cavities the formation of which is attributed to processes such as fatigue, local adhesion, or cavitation. **G40**

3.1.19 *rolling, v—in tribology*, 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**

3.1.20 *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**

3.1.21 *run-in, n—in tribology*, initial transition process occurring in newly established wearing contacts, often accompanied by transients in coefficient of friction, or wear rate, or both, which are uncharacteristic of the given tribological system's long term behavior. (Synonym: *break-in*, *wear-in*.) **D4175, G40**

3.1.22 *run in, v—in tribology*, to apply a specified set of initial operating conditions to a tribological system to improve its long term frictional or wear behavior, or both. (Synonym: *break in*, v, and *wear in*, v.) See also *run-in*, n) **G40**

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

3.1.24 *scoring, n—in tribology*, severe form of wear characterized by the formation of extensive grooves and scratches in the direction of sliding. **D4175, G40**

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

3.1.26 *soot, n—in internal combustion*, engines, sub-micron size particles, primarily carbon, created in the combustion chamber as products of incomplete combustion. **D4175**

3.1.27 *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**

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

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

3.1.29 *triboelement, n*—one of two or more solid bodies that comprise a sliding, rolling, or abrasive contact, or a body subjected to impingement or cavitation. (Each triboelement contains one or more tribosurfaces.)

3.1.29.1 *Discussion*—Contacting triboelements may be in direct contact or may be separated by an intervening lubricant, oxide, or other film that affects tribological interactions between them. **G40**

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

3.1.31 *viscosity, n*—ratio between the applied shear stress and rate of shear. It is sometimes called the coefficient of dynamic viscosity. This value is thus a measure of the resistance to flow of the liquid. The SI unit of viscosity is the pascal second (Pa.s). The centipoise (cP) is one millipascal second (mPa.s) and is often used. **D4175**

3.1.32 *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. **G40, D4175**

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 generated due to hard, abrasive particles present between wearing surfaces of unequal hardness.

3.2.1.1 *Discussion*—Sometimes called cutting wear particles.

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 *bichromatic microscope, n*—optical microscope equipped with illumination sources both above and below the microscope stage such that objects may be viewed either with reflected light, or with transmitted light, or with both simultaneously.

3.2.4 *black oxides of iron, n*—generally small, black clusters with pebbled surfaces showing small dots of blue and orange color. These are nonstoichiometric compounds containing a mixture of Fe_3O_4, Fe_2O_3 and FeO.

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

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

3.2.7 *corrosive wear debris, n*—extremely fine partially oxidized particles caused by corrosive attack.

3.2.8 *dark metallo-oxide particles, n*—partially oxidized ferrous wear particles indicating high heat during generation most likely due to lubricant starvation.

3.2.9 *entry, n*—entry area of the ferrogram, region where the sample first touches down onto the glass surface of the ferrogram and where the largest ferrous particles are deposited.

2

3.2.10 *ferrograph, n*—apparatus to magnetically separate and deposit wear and contaminant particles onto a specially prepared glass microscope slide.

3.2.11 *ferrogram, n*—specially prepared glass microscope slide that has ferrographically deposited particles on its surface.

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

3.2.13 *friction polymers, n*—these are characterized by small metal particles embedded in an amorphous matrix.

3.2.14 *nonferrous metal particles, n*—free metal particles composed of any metal except iron. All common nonferrous metals behave nonmagnetically except nickel.

3.2.15 *nonmetallic particles, n*—particles comprised of compounds, organic material, glasses, etc., that have bound electrons in their atomic structure.

3.2.16 *nonmetallic amorphous particles, n*—particles without long range atomic order that are transparent and that do not appear bright in polarized light.

3.2.17 *nonmetallic crystalline particles, n*—particles with long range atomic structure that appear bright in polarized light. These may be single crystals but are most likely polycrystalline or polycrystalline agglomerates.

3.2.18 *platelets, n*—flat, free metal wear particles that are longer and wider than they are thick. They have a major dimension-to-thickness ratio in the range of approximately 5:1 to 10:1 or more.

3.2.19 *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.

3.2.20 *red oxide sliding particles, n*—sliding wear particles that appear gray in reflected white light, but are dull reddish-brown in white transmitted light.

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 these are formed by the passage of a wear particle through a rolling contact.

3.2.22 *rolling contact fatigue particles, n*—flat platelets, with their 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.

3.2.23 *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 and 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.

3.2.24 *severe sliding wear particles, n*—severe wear particles displaying surface striations and straight edges.

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

3.2.26 *spheres, n*—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.

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

4. Summary of Practice

4.1 Periodic in-service lubricant samples are collected from a machine or engine as part of a routine condition monitoring program. A ferrogram is prepared from the sample to separate particles from sample fluid. The ferrogram is 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, a ferrogram is not prepared for every sample taken, but may be prepared when routine tests such as spectrochemical analysis, particle counting or ferrous debris monitoring indicate abnormal results.

4.3 The user of this practice employs consistent terminology to achieve accepted and understandable interpretations when communicating instructions and findings based on ferrographic analysis.

5. Significance and Use

5.1 The objective of ferrography 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 practice describes commonly found particles in in-service lubricants, but does not address methodology for quantification of particle concentration.

5.2 This practice is provided to promote improved and expanded use of ferrographic analysis with in-service lubricant analysis. It helps overcome some perceived complexity and resulting intimidation that effectively limits ferrographic 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 Ferrographic analysis, as described in this practice, provides additional particle identification capabilities beyond methods described in Guide D7684 for the following reasons:

(1) The ferrographic particle separation method is magnetic thus making it possible to readily distinguish between ferrous and nonferrous wear particles.

(2) Ferrography separates ferrous (magnetic) particles by size.

(3) Deposition is on a glass substrate so that particles may be examined using transmitted light as well as reflected light allowing particle types to be identified that cannot be identified when examination is done using only reflected light.

(4) Ferrograms may be heat treated providing important distinctions between ferrous alloy types (steel versus cast iron), further distinctions among various nonferrous alloys and distinctions between inorganic and organic particles.

5.5 Caution must 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. Apparatus

6.1 *Required Components:*

6.1.1 *Ferrograph or Ferrogram Maker*—Apparatus for magnetically separating particles from fluids.

6.1.2 *Bichromatic Microscope*—An optical microscope is required with dry metallurgical objective lenses and equipped with a reflected light source and a transmitted light source so that objects may be viewed from both above and below the microscope stage. This permits objects to be viewed either with reflected light, or with transmitted light, or with both simultaneously. Bichromatic microscopes for ferrogram examination are required to be equipped with three objective lenses to give varying degrees of magnification. The low magnification objective lens is typically 10×, the medium magnification objective lens may be 40× or 50× and the high magnification objective lens may be 80× or 100×. Ten power (10×) ocular (eyepiece) lenses are used such that total magnification achieved is 100× at low magnification, 400× or 500× at medium magnification and 800× or 1000× at high magnification. The numerical apertures of the objective lenses need to be high to maximize illumination of particle surfaces when viewed in reflected light. It is required to be able to polarize either light path to facilitate particle identification. Polarized light aids in the identification of nonmetallic particles. A red filter is required to be optionally placed in the reflected light path and a green filter is required to be optionally placed in the transmitted light path. The simultaneous use of red reflected and green transmitted light aids in the distinction between metallic and nonmetallic particles. One of the ocular lenses should be fitted with a calibrated scale so that length of objects may be measured. The stage drive of the microscope should be fitted with calibrated divisions so that thickness of objects may be measured as the stage is raised or lowered.

6.1.3 *Blank Ferrogram Glass Substrates*—A supply of specially prepared microscope slides with nonwetting barriers to contain sample flow in the central portion of the substrate are required.

6.1.4 *Precision Pipettor*—A pipettor capable of delivering a precise volume of 1 mL of viscous fluid is required.

6.1.5 *Mixing Vials*—Clean vials, usually 12 mL capacity, are needed to mix sample with solvent prior to processing by the ferrograph.

6.2 *Optional Components:*

6.2.1 *Hot Plate*—A hot plate capable of achieving surface temperatures of 540°C is required if it is desired to heat treat ferrograms to further identify the metallurgy of metal particles.

6.2.2 *Surface Thermometer*—A surface thermometer capable of measuring to 540°C is needed for heat treating ferrograms.

6.2.3 *Tongs*—Tongs are needed to remove the heated ferrogram from the hot plate.

6.2.4 *Camera*—The microscope may be equipped with a suitable camera for taking photomicrographs for reporting and documenting purposes.

7. Reagents

7.1 *Heptane*—The recommended solvent is heptane, but other solvents may be used if they meet the following criteria:

7.1.1 The solvent must be a good oil solvent.

7.1.2 The solvent cannot be too volatile. If the solvent evaporates too quickly the strings of particles on the ferrogram surface will be pulled out of place by the movement of the quickly drying solvent.

7.1.3 If the solvent evaporates too slowly, excessive time will be spent waiting for the ferrogram to dry.

7.1.4 The solvent needs to be residue and particle-free. Prepare a ferrogram using only solvent and examine it under the microscope to make sure the ferrogram surface is clean. From a practical viewpoint, it will be almost impossible to prepare a blank ferrogram, that is, one that is totally free of particles. Therefore, some judgment should be exercised regarding an acceptable cleanliness level. A few small nonmetallic particles are tolerable in that they would not interfere with evaluation of machine condition. On the other hand, if the blank ferrogram has metallic particles deposited on it, then steps need to be taken to eliminate the source of contamination. It may be necessary to filter the solvent through a submicron membrane filter to remove particulate contaminants or to let the solvent remain undisturbed for overnight or longer so that particles settle to the bottom of the bottle or container. Withdrawing solvent from near the top of the undisturbed container will likely yield particle free solvent.

8. Sampling and Sample Handling

8.1 *Sample Acquisition*—The objective of sampling is to obtain a test specimen that is representative of the entire quantity. Thus, laboratory samples should be taken in accordance with instructions in Practice D4057.

9. Procedure

9.1 *Ferrogram Preparation:*

9.1.1 *Sample Preparation*—Laboratory samples should be shaken or agitated to ensure a representative sample is taken from the sample bottle.

9.1.2 In-service lubricating oil samples must be diluted with solvent to lower their viscosity before the sample is allowed to flow onto the substrate. If the solvent is particle free, it does not matter how much solvent is used to dilute the oil sample. The purpose of the dilution is to make the solvent/sample mixture have a viscosity such that it flows onto the ferrogram at an approximate rate of 0.4 mL/min. Experience indicates that an ISO 68 oil (an oil having a viscosity of 68 centistokes (cSt) at 40°C), when diluted in the ratio of 3 parts oil sample to one part heptane, will flow at approximately 0.4 mL/min.

9.1.2.1 If the viscosity of the solvent/sample mixture is too high, the particles will be retarded in their migration through the fluid toward the magnet pole pieces. This will have the effect of allowing large ferrous particles to penetrate further along the length of the ferrogram than would normally be the case. Worse, however, from an operational viewpoint, is that the fluid will be so viscous that it will form a large crown and spill over the non-wetting barrier stripe on the ferrogram surface necessitating the ferrogram preparation process to repeated. If the solvent/sample viscosity is too low, the ferrous (magnetic) particles will migrate too quickly toward the pole pieces and many small particles will be deposited at the entry region of the ferrogram (where the fluid first touches down on the ferrogram) along with the large ferrous particles. Furthermore, the fast flow rate may cause the fluid to spill over at the exit end of the ferrogram instead of flowing into the drain tube. Therefore, some judgment is required to dilute the sample properly.

9.1.2.2 In general, oils with ISO grades up to 68 will flow properly if diluted in the ratio of 3 parts sample to one part solvent. More viscous oils require more solvent, 3 parts sample to 2 parts solvent is recommended.

9.1.2.3 To a large extent, the effect of viscosity on the deposition pattern is self-compensating. The higher the viscosity, the longer it takes for the solvent/sample mixture to flow, and the longer it takes for the particles to flow through the fluid due to the viscous resistance the particles experience. Likewise, when the viscosity is low, the sample flows down the substrate more quickly, and the particles move more quickly toward the magnet assembly because the viscous resistance they experience is correspondingly less. Therefore, the resulting deposition pattern on the ferrogram is more or less the same even though the solvent/sample viscosity varies to some degree.

9.1.3 Remove the blank ferrogram glass substrate from its plastic cover and position it so that the marking dot on the glass surface is in the lower left-hand corner of the ferrograph magnet channel. The purpose of the marking dot is to identify the side of the glass having the non-wetting barrier stripe.

9.1.4 Withdraw the spring-loaded position pin on the left side of the magnet assembly. Place the glass substrate on the magnet assembly. Position the upper end of the glass substrate so that it rests on the small step at the back of the magnet assembly slot. Allow the exit end of the glass substrate to rest on the magnet assembly surface.

9.1.4.1 This causes the glass substrate to be elevated at the entry end relative to the exit end. The purpose is to reduce the magnetic field strength at the entry end so that small particles are not deposited as quickly as they might otherwise be. This gives better separation between large and small magnetic particles as they are deposited on the substrate.

9.1.5 Gently release the positioning pin so that the glass substrate is held firmly in place against the right edge of the magnet channel.

9.1.6 Complete ferrogram preparation following specific manufacturer's instructions.

9.1.6.1 This will entail allowing the prepared solvent/sample mixture to flow slowly across the glass surface of the ferrogram slide during which time ferromagnetic particles will be deposited on the glass surface in an orderly fashion according to size. Weakly magnetic and nonmagnetic particles will be deposited randomly along the length of the ferrogram. Soot particles, as found in diesel engine lubricating oil samples, are repelled by the magnetic field of the ferrograph and flow off the ferrogram to waste. After the prepared sample has flowed completely across the ferrogram surface, the remaining sample on the ferrogram surface is rinsed using an appropriate solvent, per specific manufacturer's instructions. After rinsing, remaining solvent is allowed to dry and the separated wear and contaminant particles become firmly adhered to the glass surface of the ferrogram.

9.1.7 After the surface is completely dry, withdraw the spring-loaded positioning pin and lift the ferrogram off the magnet assembly. The ferrogram is now ready for microscopical examination.

9.1.7.1 **Caution**: The ferrogram must be lifted straight up off the magnet assembly. If the ferrogram is slid along the magnet assembly, the magnetic field will twist and distort the strings of ferrous particles on the ferrogram surface. To lift the ferrogram off smoothly, it is recommended that the exit end be lifted up first while the front end still rests on the small step at the back of the top plate slot. Once the back end has been raised approximately 2 cm, the entire ferrogram can be lifted away from the magnet assembly.

9.2 *Ferrogram Analysis Procedure:*

9.2.1 Place the ferrogram onto the stage of the microscope and begin inspection of the particles thereon. Table 1 summarizes the suggested procedure for analysis of a ferrogram. Step 1 suggests viewing of the ferrogram at low magnification with red reflected and green transmitted light. At this time, it may be determined whether the deposit on the ferrogram is too heavy for proper particle identification. If the deposit at the ferrogram entry is so heavy that particles are piled on top of one another it will be very difficult to determine the types and relative amounts of particles present. Some piling up is tolerable, but strings of ferrous particles should be separated and ideally particles should be deposited in a single layer. If too many particles are present, it is recommended that the sample be diluted 9:1 with particle free oil and a new ferrogram be prepared with 3 mL of the diluted sample. This will result in a ferrogram prepared from 0.3 mL of sample, rather than the standard 3 mL sample volume. It may happen that the ferrogram prepared from 0.3 mL of sample again has too many

TABLE 1 Suggested Procedure for Analysis of a Ferrogram

Step	Magnification	Reflected	Transmitted	Comments
1	100× (low)	Red	Green	View the entry region to determine if too many particles are deposited on the ferrogram. If so, a new ferrogram needs to be prepared from diluted sample. Otherwise, proceed to Step 2.
2	100× (low)	Red	Green	Look for severe wear particles at entry by presence of bright red particles. Rubbing wear particles are too small to be resolved at this low magnification and appear black. Therefore, if only rubbing wear particles are present on the ferrogram, no red particles will be observed. Large wear particles will appear bright red against an otherwise green background. Scan length of ferrogram looking for severe nonferrous wear particles, nonmetallic particles, or a heavy deposit at the exit end typical of corrosive wear.
3	400× or 500× (medium)	White	Green	Examine the entry deposit making a preliminary judgment as to the specific types of wear particles present such as severe wear, rubbing wear, chunks, etc. A preliminary judgment of dark metallo-oxides must be confirmed at high magnification because particles that are not flat will appear dark. Scan the length of the ferrogram looking for nonferrous metal particles and other distinctive features such as nonmetallic particles, friction polymers, fibers, etc.
4	800× or 1000× (high)			Most particle types can be recognized at medium magnification, but high magnification provides critical details necessary to complete the analysis. Spheres, fine cutting wear particles and small spots of temper color on the surfaces of particles indicative of high heat during generation can be distinguished only at high magnification. Because of the high numerical aperture of the highest magnification lens that provides good light gathering ability, jagged free metal particles may be distinguished from dark metallo-oxides. Friction polymers are recognized by the presence of fine metal particles in an amorphous matrix whereas nonmetallic amorphous particles do not contain fine metal particles. Red reflected and green transmitted light is useful for identifying friction polymers because of the greater contrast provided.
5	100× (low)	OFF	POL	Use polarized transmitted light to identify nonmetallic crystalline particles. These will appear bright in an otherwise dark field.
6	400× or 500× (medium)	POL	OFF	Use polarized reflected light to determine surface characteristics of particles. Oxidized surfaces of metal particles will depolarize light and thus appear bright. Small nonmetallic particles which may not have been seen at 100× can now be detected. Use high magnification with polarized reflected light if surface characteristics are of particular interest.
7	As Required			Take photos prior to heat treating ferrogram. A polarized light photo may be useful if it is desired to distinguish between organic and inorganic particles. Organic particles will not be as bright after heat treatment. A second photo using the same exposure will show this difference. It may also be useful to photograph strings of ferrous particles before heat treatment as well as any suspected Pb/Sn alloy particles
8				Heat treat ferrogram. (Optional)
9	As Required			Reexamine ferrogram after heat treating. Take photos as necessary

particles in which case a further 9:1 dilution should be made from the already diluted sample and another ferrogram prepared. In this case, the resulting ferrogram will have been made from 0.03 mL of sample. In rare circumstances, the sample may have to be diluted yet again. Once it is determined that the ferrogram under examination has an acceptably dilute deposit, proceed to Step 2 on Table 1.

9.2.2 At low magnification using red reflected and green transmitted illumination, large wear particles will appear bright red because of their highly reflective surfaces. Wear particles are metallic except for some few special machines that use nonmetallic components in the oil-wetted path, such as diesel engines with ceramic pistons. Metallic particles always block light, even in exceedingly thin sections. Therefore, metals may be recognized because they block transmitted light. Very often, metal wear particles are present as free metal (not compounded with other elements, such as oxygen) and will therefore have bright, lustrous reflective surfaces. Nonmetallic particles (see 3.2.15) appear partially green because they permit the transmission of light.

9.2.2.1 Metallic particles, even when extremely thin, block the passage of light. Conversely, nonmetallic materials, at least in thin sections such as would be found in oil samples in the few to tens of μm thick range, allow passage of light and therefore appear partially transparent when examined using transparent light. Nonmetallic polycrystalline particles, such as sand (primarily SiO_2), disrupt polarized light and therefore

appear bright in an otherwise dark field. Nonmetallic amorphous materials, such as glass or many organic materials, do not disrupt polarized light and therefore remain dark.

9.2.2.2 For common machines, engines and hydraulic systems, most components are composed of iron (ferrous) alloys, that is, steel or cast iron. These particles are magnetic and are separated preferentially on a ferrogram. The largest ferrous particles are deposited near the entry area of the ferrogram, that is, where the sample first touches down onto the glass surface of the ferrogram. As the sample travels down the length of the ferrogram, the ferrous particles deposited become smaller and smaller. By the exit end of the ferrogram, they are submicron in size. Ferrous particle are deposited in strings by the magnetic field of the ferrograph, with their ends touching and their longest dimension perpendicular to the direction of flow along the ferrogram. See Fig. 1.

9.2.2.3 Nonferrous metal wear particles are identified by their nonmagnetic deposition pattern on ferrograms. Instead of aligning with the magnetic field in strings as do ferrous particles, nonferrous particles are deposited with random orientation and may be found along the entire length of the ferrogram regardless of size. By examining the length of the ferrogram at low magnification with red reflected and green transmitted light, large nonferrous metal wear particles will be obvious because they will appear bright red against an otherwise green background.