

Analytical Ferrography Applied to Driveline Fluid Analysis

Timothy Newcomb and Mark Sparrow*

BorgWarner, Inc.

Copyright © 2008 SAE International

ABSTRACT

Analytical ferrography of used oils is most often associated with machine maintenance programs where it is used as a predictive tool to avoid catastrophic failures. The technique is not widely used in driveline fluid evaluations, likely due to both its expense and a general unfamiliarity of the technique among engineers and scientists involved in driveline fluid analysis. However, this technique can provide data essential to understanding the degraded performance of the friction interface.

In this paper we briefly describe analytical ferrography. We then show three circumstances where the use of this technique is appropriate for the evaluation of used driveline fluids. First we illustrate how analytical ferrography can be used to detect the past presence of water in oil that is currently dry. Next we show how the technique can help identify contaminant particles that would normally remain undetected due to size and low abundance. Finally we demonstrate how this technique can be used to identify friction material debris.

We close with an amusing example of an odd-looking contaminant found during a routine oil analysis.

INTRODUCTION

The evaluation of used oil is an essential part of understanding degraded or poor performance of a friction interface. Often the analyses chosen to provide data for this evaluation consist of a combination of ICP (Inductively Coupled Plasma) or other 'metals' analysis, viscosity measurements, and the determination of TAN (Total Acid Number) and TBN (Total Base Number) values. Occasionally the evaluation will also include particle counts, water content or infrared spectroscopy. When the fluid is transmission oil, a friction test is usually conducted to evaluate the condition of the friction modifier system.

Analytical ferrography is not often employed in evaluating used oil from automatic transmission applications. The strength of this technique is its ability to differentiate abnormal (metal) wear conditions

whereas transmission failures are usually related to the degradation of the lubricant or the friction plate. The method is also expensive and there is a general unfamiliarity of the technique among transmission engineers and scientists. However this technique can provide crucial information about key aspects of the friction system not easily gleaned from the standard methods employed to evaluate used transmission fluids.

In this paper we provide a brief description of analytical ferrography and then show how the method can be used to identify the past presence of water in oil, the detection of abrasive media in the presence of large amounts of wear metal and the identification of friction material wear.

Finally, we show an unusual particle observed during a routine oil analysis that appears to be insect contamination.

DESCRIPTION OF ANALYTICAL FERROGRAPHY

The ferrograph was developed by Vernon C. Westcott in the 1970's [1] and was first used by the US military to detect bearing damage in aircraft prior to the onset of catastrophic failure [2]. The method rapidly evolved and is well described in the literature [3-5]. There are two forms of ferrography; direct reading ferrography and analytical ferrography. Direct reading ferrography uses optical density to measure the concentration of large and small wear particles. Analytical ferrography examines the particulates in lubricants using various forms of microscopy.

In analytical ferrography, the particles in a fluid are deposited on a glass slide and then characterized (analyzed) using microscopy. Typically bichromatic light microscopy is used, but scanning electron microscopy (SEM), sometimes in conjunction with energy dispersive x-ray analysis (EDS), is also used.

The ferrogram is made by flowing a contaminated fluid across a glass slide at a slow but constant rate under a magnetic field. Normally a specialized instrument, a

* Now at RJ Lee, Pittsburgh, PA

ferrograph, is used for this purpose. An early version of a ferrograph is shown in Figure 1. The ferrograph is equipped with a pump for transporting the fluid from a sample holder, through a Teflon tube, to the glass slide.



Figure 1. Dual ferrogram maker (vintage 1970s)

The glass slide is positioned on top of the magnet in order to isolate ferrous wear metal particles, as shown in Figure 2. The glass slides have a barrier to confine the fluid to a band down the middle of the slide. As the fluid flows down the slide, ferrous wear metal and other debris are deposited. Due to the magnetic field under the slide, the ferrous wear metal deposits along the magnetic lines of force. A typical ferrogram slide is shown in Figure 3. The largest iron wear particles are deposited at the entry point of the ferrogram slide with the remaining particulates deposited in order by size from largest to smallest on down the slide. In this manner, the sizes and morphologies of the ferrous wear particulates can be determined.

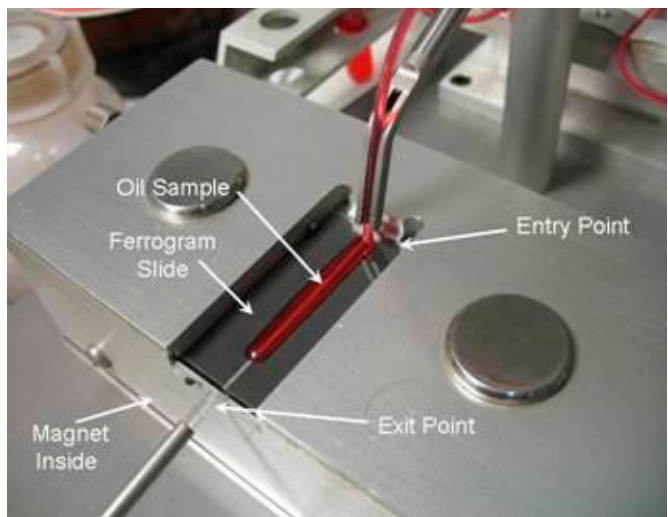


Figure 2. Working unit where the particles within the fluid are deposited. The slide is positioned over a magnet and generally at a small incline.

Other non-magnetic particulates are distributed throughout the slide and an appropriate solvent is flowed over the particles to remove the remnants of the test fluid. The slide is dried and ready for analysis.

Optical microscopy provides a fast means of characterizing the particles on the ferrogram. It is

possible to distinguish between the various types of wear metal particulates such as rolling, cutting, sliding and spalling wear based on particle shape. Heating the slide (2 minutes at 315°C) will alter the color of babbitt (alloys of tin, antimony, copper and lead), low alloy steel and cast iron, allowing these to be uniquely identified.

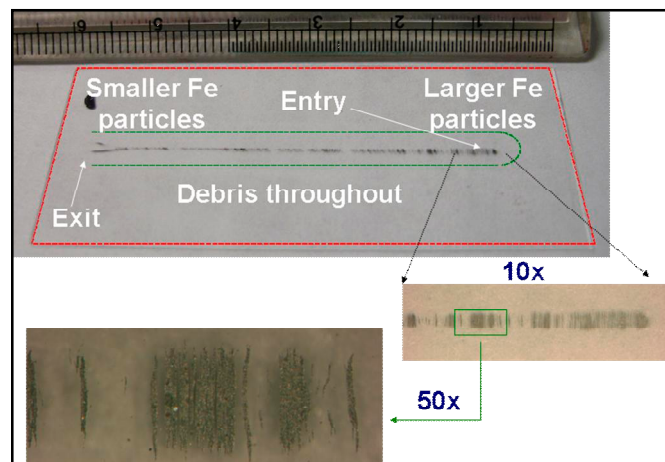


Figure 3. Photograph of a ferrogram with magnified views of the slide.

Traditional analytical ferrography uses bichromatic illumination to characterize the particles. Overhead red light illuminates that particle field and green light provides back illumination. This is illustrated in Figure 4. Under this lighting scheme, reflective metal particles are readily differentiated from translucent oxides or polymeric materials. A ferrogram under this illumination is shown in Figure 5.

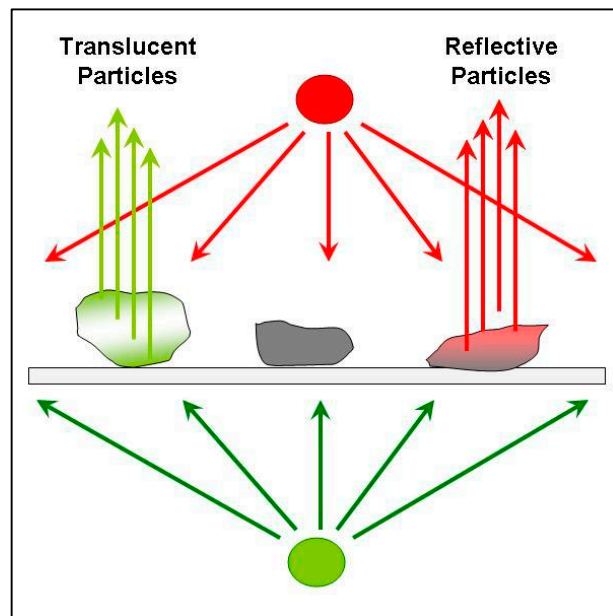


Figure 4. Standard Illumination for viewing ferrogram.

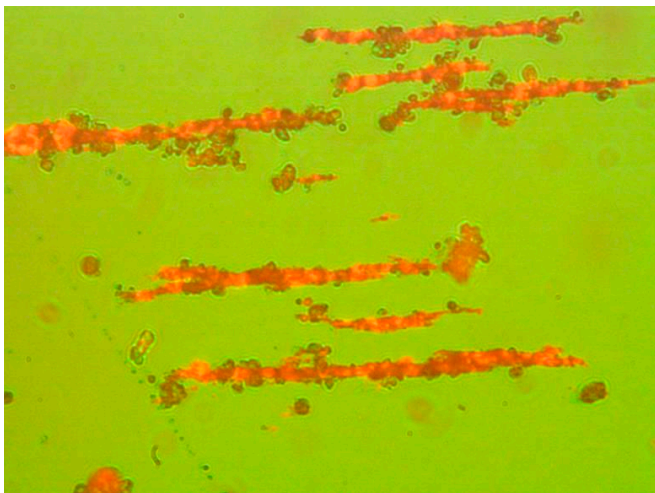


Figure 5. Ferrogram under standard (red/green) illumination.

However, various other illumination schemes can be employed when using light microscopy. Darkfield and brightfield illumination are most common. Darkfield illumination is most useful for generating image contrast between the wear particulates and the slide itself. Ferrous wear metal particulates will appear shiny and silvery under darkfield illumination while color in non-ferrous particulates is enhanced. Cross-polarized illumination is also employed to further enhance the contrast of non-ferrous particulates while slightly suppressing the contrast of the ferrous particulates. Cross polarized illumination is particularly useful when looking for non-ferrous particulates or metal oxides as their colors can be easily distinguished.

When it is important to determine the particle elemental composition unequivocally, SEM and EDS analysis can be used. This is particularly important when trying to distinguish between different types of non-ferrous particulates. When using SEM as an analysis tool, ferrogram slides made of carbon instead of silica glass can be used in order to facilitate the analysis and prevent charging of the sample.

The use of optical, SEM and EDS analysis techniques together provides comprehensive information on wear particles in fluids, such as detailed particle morphology and elemental composition that can help identify sources of such non-metallic particulates.

DETECTION OF HISTORIC WATER IN DRY OIL

There are several methods available for determining the water content of oil. The most commonly used are perhaps the Karl-Fischer method, reaction with calcium hydride, infrared spectroscopy and the water crackle test [6]. These techniques all provide a measure of the water currently present in oil. However, transmissions and other mechanical driveline devices can, at least some of the time, operate at temperatures sufficient to expel water.

Presence of Red Oxides in Ferrogram

The presence of red oxides in oil indicates water contamination [7]. Figures 6 and 7 provide examples of the appearance of red oxides on a ferrogram. In the case of Figure 6, the oil contained considerable water content as measured using a water crackle test. In Figure 7, the water content, as measured by the Karl-Fischer method was negligible.

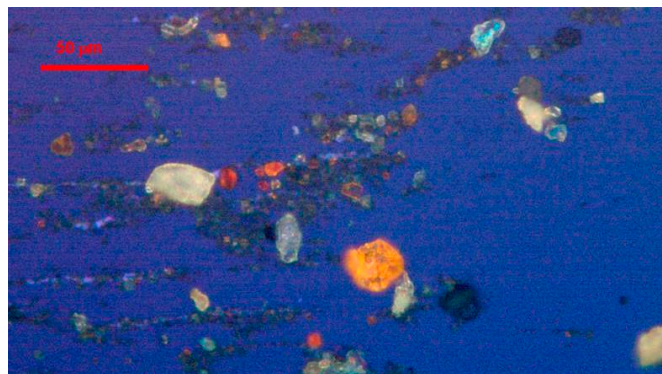


Figure 6. Images from a ferrogram made from engine oil. The oil contained >0.2% water (determined by water crackle test). Image was taken under cross-polarized light.

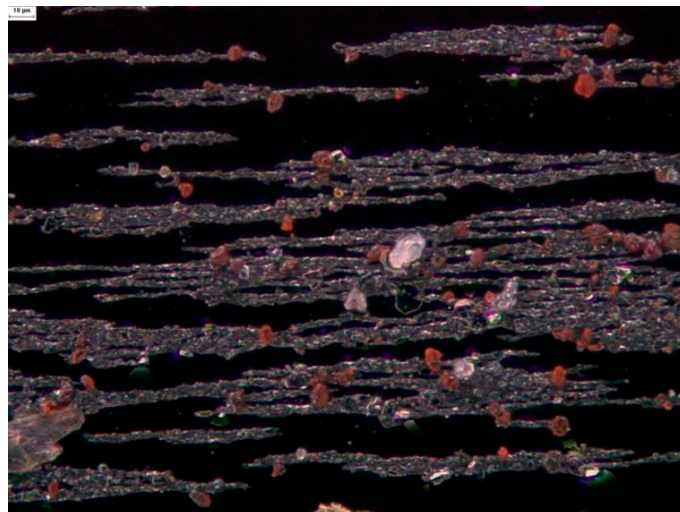


Figure 7. Darkfield image from a ferrogram made from transmission fluid showing red oxides of ~ 10 micron diameter. The white particles are abrasive oxides attributed to dirt ingress.

These figures illustrate a key point of water detection by analytical ferrography: the water does not have to be present in the oil at the time of the analysis to confirm it was present at some point during the oil's history.

It is therefore prudent, especially in cases where the failure mode is consistent with water contamination, to look for the presence of red oxides in the oil when the traditional methods show little water currently present.

Water contamination and friction material de-bonding

Friction material is bonded to metal cores using a fully cross-linked, chemically inert resin. Under rare circumstances of prolonged use in oil contaminated with high levels of water or coolant the bond between the friction lining and the core plate can weaken. In some such cases, the friction lining has been known to separate from the core plate [8].

Figure 8 shows an example of this type of de-bonding. Here the bond between the friction material land areas was weakened such that the lining could be easily removed by a razor blade. The bond between the metal and molded material groove area, however, remained relatively intact. The molded groove is made by compressing the friction material and hence the material below the groove is denser, and less permeable, than the land areas.

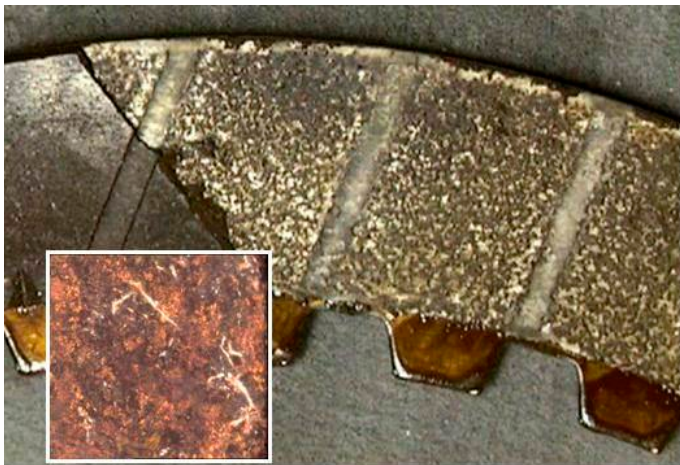


Figure 8. Example of friction material de-bond showing the impression of the lands wherein the moisture preferentially wicks. Inset is color image of rust from the core plate region originally under a land.

The water reaches the interface by wicking through the friction material at its most permeable areas, the lands, and then penetrates through the resin. Water concentrating at the metal surface can cause the formation of rust. In Figure 8 the formation of rust is preferential to the area directly under the lands of the friction material.

Friction material de-bonding in the apparent absence of water

Understanding the de-bonding of material from the core plate is not as straight forward when water is not present in the oil. This is illustrated by the following case.

During routine maintenance several industrial transmissions were found to have de-bonded friction linings. Three units were evaluated for weakened friction material – core plate bond strength using a plate

bend test [9]. The appearance of the core plates exposed by the bend test and the water content (by Karl-Fischer method) of the oil samples from each unit are depicted in Figure 9. The friction plates from two of the units failed the bend test while one passed.

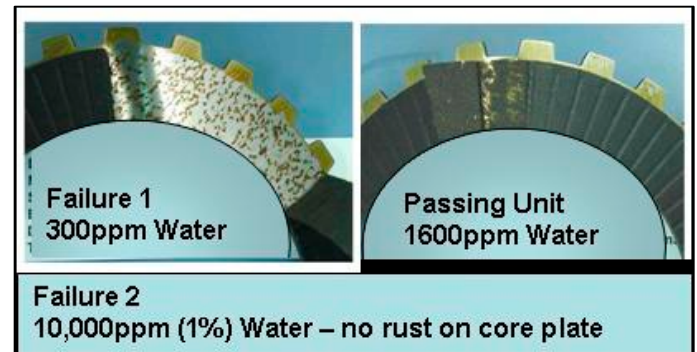


Figure 9. Photographs of parts after bend test (Failure 2 image not available) with corresponding water content.

As is evident in Figure 9, rust is present on the core plate of failure 1. However, the water concentration present in the corresponding oil was typical of a dry transmission fluid, < 300ppm water. On the other hand, the friction material from failure 2 (image not available) separated easily from the core plate. No rust evident on the metal surface even though the water content was 10,000ppm. The passing unit showed good friction material – core plate bond strength and 1600ppm water. With these data, there appears to be no correlation of water content with the de-bonding of the friction material from the core plate. The cause would appear to be related to another mechanism.

When the fluids from these units were investigated using analytical ferrography, red oxides were found in oil samples from the passing unit and, more telling, the failure 1 unit. Very little red oxide was detected in the oil from the failure 2 unit. Ferrograms to document these findings of the red oxides are shown in Figure 10. A complete summary of the ferrographic analysis is presented in Table I.

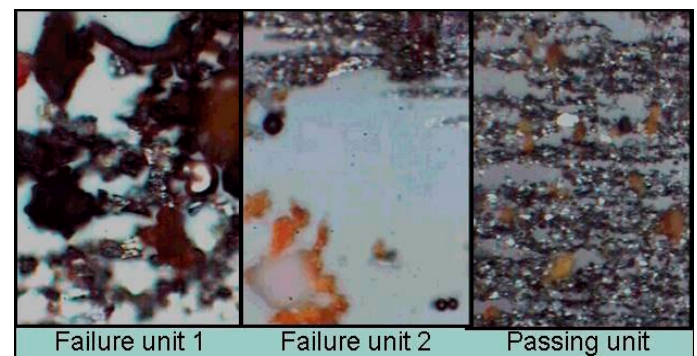


Figure 10. Ferrographic images selected to show red oxides present in used oil samples.