

The Effect of Lower Viscosity Automatic Transmission Fluid on Glaze Chemistry

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ABSTRACT

One of the most common failure modes for a friction interface is the accumulation of glaze on the friction material surface. Until recently, our analysis of glaze chemistry has always been consistent with the degradation of detergent, antiwear and extreme pressure additives in the oil. These additive degradation products are readily identified by the presence of Ca, P, S and Zn in an EDS analysis. In these cases the loss of friction performance, characterized by a gradual fade in friction coefficient and the concomitant development of a negative friction-speed gradient, is directly related to the loss of surface porosity due to the accumulation of glaze on the friction material surface.

Over the past few years, the drive for better fuel economy in passenger cars has led to the introduction of lower viscosity oils possessing high viscosity index and shear stability. We have observed that these fluids also can lead to glaze accumulation on the friction surface. However, for these new oils, under certain conditions, the glaze is a consequence of the viscosity modifier additives. The association of the glaze to this additive type is more difficult to establish due to the absence of unambiguous indicator elements. To correctly identify the additive chemistry responsible for this glaze we have used Evolved Gas Analysis; a technique involving the volatilization of the glaze and subsequent identification using a coupled Gas Chromatograph – Mass Spectroscopy technique.

In this paper we contrast the glaze chemistry arising from conventional fluids (traditional ATF viscosity) with that of the newer, lower viscosity fluids. We provide data suggesting that the failure mode is not only related to the accumulated loss of surface porosity but also the deactivation of the friction surface (loss of surface active sites). We then discuss how this new fluid chemistry influences the formulation of new friction materials.

INTRODUCTION

It is our experience that the most common failure mode for friction plates is the formation of glaze on the friction material surface. As the glaze accumulates, it reduces the surface porosity which can then result in the development of a negative friction-speed gradient (rooster tail) [1]. It is known that glaze originates from the fluid [2, 3, 4]. Previously we have specifically defined glaze as the deposition of fluid degradation products on the friction material surface and described a set of analytical protocols to detect and quantify the glaze [3].

Among the methods employed to detect and quantify glaze, EDS (Energy Dispersive X-ray Spectroscopy) is used to identify the presence of elements associated with the lubricant additive package. These elements, Ca, P, S and Zn, are readily detected with EDS and indicate the presence of detergent, antiwear and extreme pressure additive degradation products on the friction surface.

Antiwear and Extreme Pressure additives are designed to react with metal surfaces at elevated temperatures. Dithiophosphate antiwear additives thermally decompose at temperatures below 200°C while disulfide and polysulfide extreme pressure additives thermally decompose above 200°C [5]. During engagements and continuous slip conditions, clutch interfaces can reach instantaneous temperatures in excess of 300°C. This is well above the stability of lubricant components and specifically is above the decomposition temperatures of the antiwear and extreme pressure additives. Glaze formation therefore is generally associated with thermal events. Prolonged exposure to elevated interface temperatures leads to thermal degradation of additives and their subsequent deposition onto the friction material surface. It is not surprising then, that the fluid's propensity to glaze is related to the thermal stability of the antiwear and extreme pressure additives.

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In order to improve fuel economy, original equipment manufacturers, OEMs, have introduced lower viscosity automatic transmission fluids. Figure 1 compares the standard viscosity measurements between what we will refer to as traditional ATFs and the new, lower viscosity ATFs.

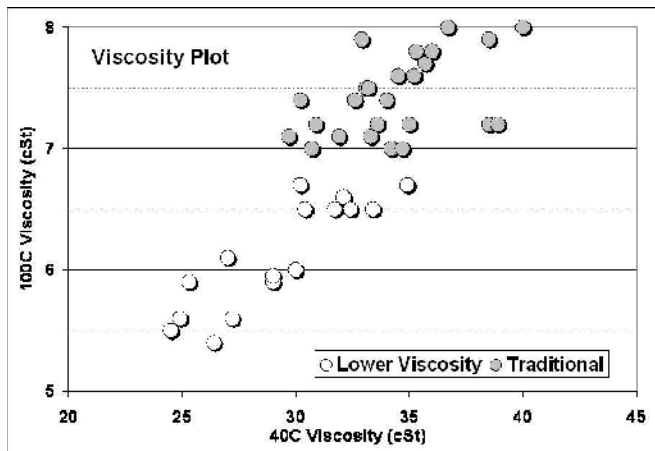


Figure 1. Comparison of traditional viscosity ATFs to newer, lower viscosity ATFs.

Traditional oils exhibit shear-down, the permanent loss of viscosity during use, by as much as 2 cSt at 100°C. However several OEMs specify that oil viscosity at 100°C cannot fall below 5.0 or 5.5 cSt during qualification trials. Consequently the starting viscosity of a fluid that will exhibit shear-down must be greater than 7 cSt. In order to meet viscosity requirements the new, lower viscosity fluids must possess greater shear stability.

Oils shear down because the viscosity modifiers (a.k.a. viscosity index improvers) break under shear stresses in gears and bearings. Viscosity modifiers are polymers that are folded upon themselves at lower temperature and unfold as the temperature is increased. As the polymer unfolds, it interacts to a greater extent with the bulk oil, effectively increasing the bulk viscosity of the fluid. Higher molecular weight polymers will be more effective in maintaining viscosity at higher temperature, but will be less stable to shear when compared with their analogous lower molecular weight counterparts. Polymethylmetacrylate (PMA) is the most commonly used viscosity modifier in driveline lubricants.

In order to reduce fluid viscosity but still maintain essential performance characteristics, several key changes are required in the construction of the ATF. The most notable changes are in the type of basestock used and the viscosity modifiers [6,7]. Use of Group II+ [8] and Group III base oils provides superior viscosity index and therefore should allow a reduction in viscosity modifier content. Several recent SAE papers illustrate the move to these improved basestocks and the implications on performance and formulation [9-16].

One major concern over the use of lower viscosity fluids is the potential loss of antiwear performance that accompanies a simple reduction in fluid viscosity.

Adjustments to the basestocks and viscosity modifiers can counter this. Itou has shown that oil film thickness increases when the molecular weight distribution of basestock is broadened. Additionally he reports that lowering the molecular weight of the PMA viscosity modifier also increases oil film thickness, as does increasing the length of the alkyl side chain [6]. Other studies have followed discussing the design of viscosity modifiers to increase film thickness and their applicability for use with lower viscosity base oils [17, 18].

Though these new base oils have the advantage of higher viscosity index, they suffer from reduced solvency. Presumably, formulating with a lower molecular weight viscosity modifier would require a greater amount (by weight) to maintain the same overall viscosity characteristic found when formulating with a higher molecular weight modifier. Considering the lower solvency of the oils used to make these lower viscosity fluids and the need to use greater concentrations of lower molecular weight viscosity modifiers, there is the possibility that the solubility of the viscosity modifier may play a critical role in the formation of this 'new' type of glaze.

GLAZE FROM TRADITIONAL OILS

Previously we have defined glaze as the deposition of lubricant degradation products on the surface of the friction material and have reported that glaze can be identified, and the severity quantified, through a combination of oil absorption, optical microscopy, SEM and EDS measurements [3]. An example of this analysis is shown in Figure 2.

The data in Figure 2 represents the standard Level I protocols we use to evaluate friction plates for glaze [3]. The stereomicrograph shown in Figure 2a gives an overview of the friction surface from the inner to outer diameter. This provides an opportunity to document breakout or major differences across the friction surface. Figure 2b gives the oil absorption measurement which is indicative of available surface porosity. The example shown here has a value at the test limit indicating that there is no accessible porosity at the friction material surface, either because of glazing or over-compression. Figure 2c shows a close-up of the material surface under darkfield illumination. The darkfield technique illuminates the sample from an oblique angle, which gives accurate color contrast and surface detail. Figure 2d shows the same view as Figure 2c but under cross-polarized light which reveals the presence of surface films resulting from heat damage or glazing. Figure 2e shows a high voltage SEM image of the friction surface whereas Figure 2f, at the same magnification, shows a low voltage SEM image of the surface and the underlying coating. Together, the images depict the material

surface porosity. Finally Figure 2g shows the EDS chemical analysis of the friction surface. The presence of Ca, P and S indicate oil degradation products. The combination of these results is used to assess the impact of the glaze on the friction material.

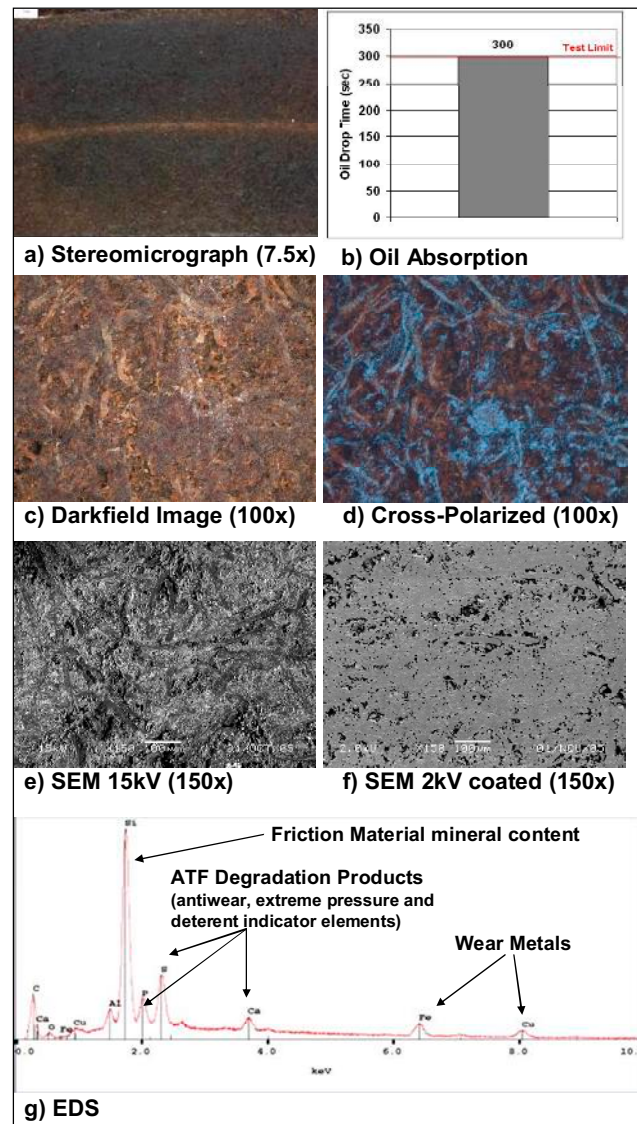


Figure 2. Example of friction material glaze analysis from a system using a traditional fluid.

The key observation linking the glaze formation to lubricant degradation is the EDS spectra that show indicator elements typical of the lubricant detergent, antiwear and extreme pressure additives. Three additional examples of EDS spectra from glazed friction material surfaces are shown in Figures 3, 4 and 5. In these cases the glaze antiwear (P, S) and detergent additives (Ca) decomposition products are evident.

Historically, our observations of glaze have always shown significant amounts of calcium, phosphorus, sulfur and when present in the oil, zinc. The amounts of these have varied depending on the application and the oil. This is illustrated by comparing the S and P peak heights, relative to Si, for the examples shown in Figures 2, 3, 4 and 5.

Because oil volumes are generally high, the deposition of additive components as glaze does not affect the bulk fluid concentrations of the additive indicator elements.

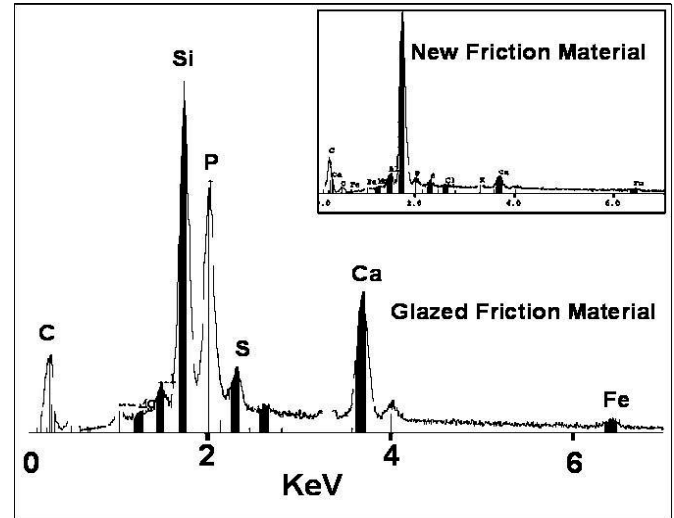


Figure 3. Example of an EDS spectrum of glazed friction material.

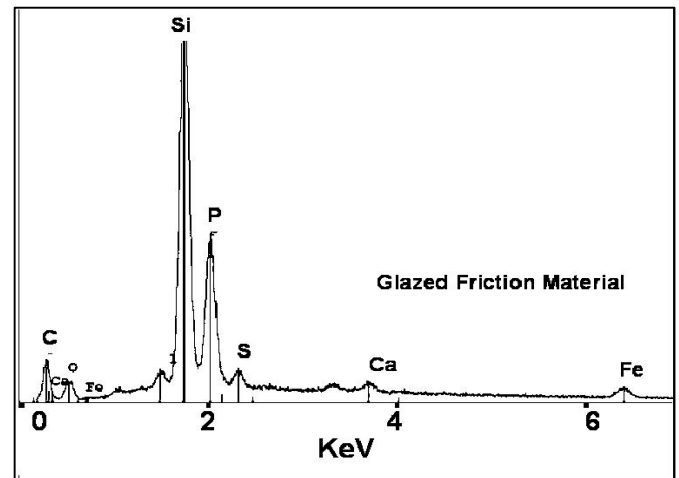


Figure 4. Example of an EDS spectrum of glazed friction material.

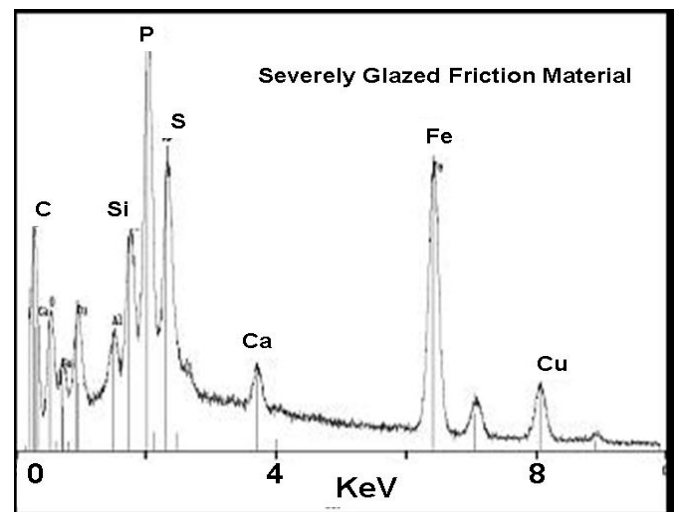


Figure 5. Example of an EDS spectrum of severely glazed friction material.

GLAZE FROM LOWER VISCOSITY OILS

We have investigated the glaze formed from six different lower viscosity fluids on friction materials taken from both bench tests and vehicles using our Level I protocols. In general they yield similar results to glazes from traditional oils except for the absence of indicator elements observable by EDS. This makes the origin of the glaze uncertain.

A typical Level I analysis of a part glazed during test with one of the new, lower viscosity oils is shown in Figure 6. This analysis mimics the one shown in Figure 2 with the exception that there is little EDS evidence to link the glaze shown in the optical and SEM micrographs to the fluid. The values of P and S, while present, are unusually low for material with this level of surface obstruction and clear micrograph evidence of glaze accumulation on the surface.

In order to understand the nature of the glaze in these cases we needed a technique that did not rely on the indicator elements, but rather could elucidate the chemical structures present on the friction surface.

EVOLVED GAS ANALYSIS

In 2005, we developed methods for using evolved gas analysis – gas chromatography – mass spectrometry (EGA-GC-MS) to chemically separate, identify and quantify components in the friction material. This is a highly advanced technique that allows verification of the intended material composition as well as identification of contaminants.

Figure 7 illustrates the operation of the EGA-GC-MS technique. First material is volatilized using a furnace and an inert carrier gas (I). The sample is dropped into the furnace at a selected temperature. This allows the constituents to be instantly volatilized, providing clearer separation of lower and higher temperature components. The volatiles are then passed directly into a gas chromatograph (II) that separates the components based on their chemical nature. This gives a GC-trace wherein each chemical species will have its own retention time and the traces can be used for sample to sample comparisons. Each peak eluting from the gas chromatograph is then analyzed with a mass spectrometer (III) that identifies the specific chemical entity based on known mass fragmentation patterns.

In 2006 we began to apply this method to evaluate friction material glaze. Operating the furnace at 750°C results in the volatilization of all friction material components (except refractory minerals) and glaze constituents. To simplify the GC trace for data interpretation, we made use of the fact that fluid constituents are less thermally stable than the friction material components. We found that operating the furnace at 400°C allowed us to analyze the fluid glaze constituents while minimizing the friction material components present in the chromatograph (cellulose

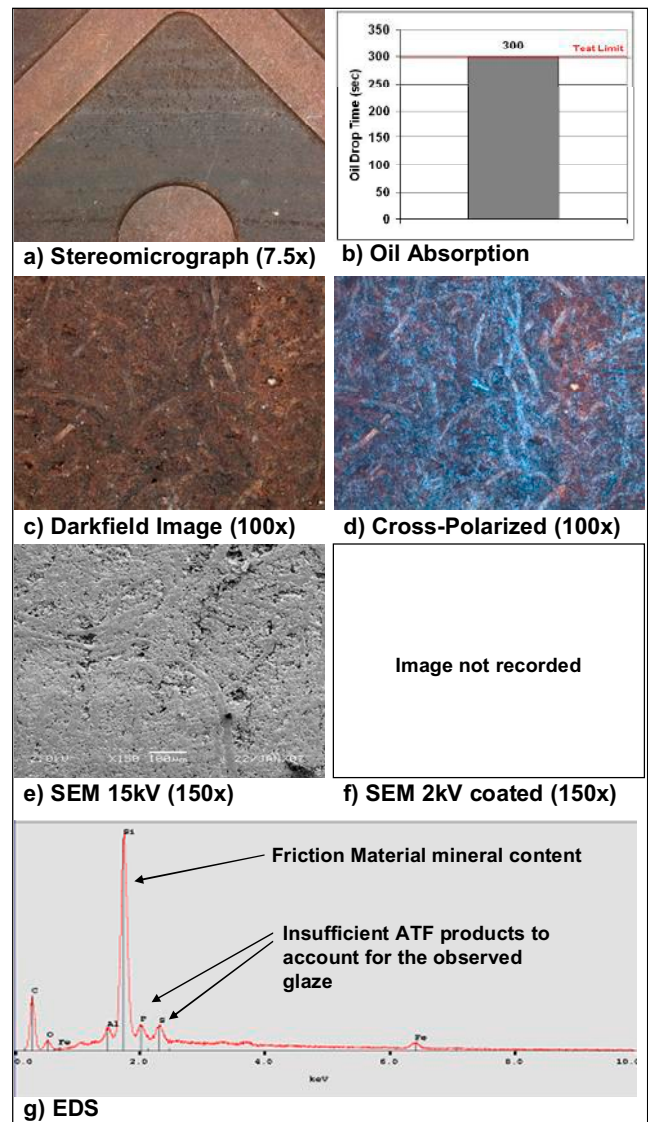


Figure 6. Example of friction material glaze analysis from a system using a lower viscosity fluid.

only). We also use this condition when analyzing the additive packages of new and used fluids [19].

The EGA-GC-MS analysis of the glaze from the same sample illustrated in Figure 6 is shown in Figure 8. This figure shows the gas chromatograph with the peaks identified using mass spectroscopy. The mass spectra are compared against a commercially available library as well as compounds we have added as reference. In addition to the viscosity modifier, there are components that are simply alkane chains that we have identified simply as 'base oil components' though they may correspond to other species. In this particular example there is also an unknown constituent.

A second example of EGA-GC-MS analysis of glaze resulting from the use of another lower viscosity oil is shown in Figure 9. In this case four GC peaks mark the viscosity modifier, rather than two. This suggests that a different construction of the methacrylate chemistry was used in this oil.