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NEW FRICTION DURABLE ADDITIVE TECHNOLOGY AND ITS APPLICATION IN AUTOMATIC TRANSMISSIONS

Abstract

This paper reports the development of a new additive technology allowing formulation of mineral oil based Automatic Transmission Fluids (ATFs) with significantly improved friction durability. The paper compares friction performance of the new additive technology with commercially available European, Asian and North American style ATFs in industry standard friction tests such as the SAE No'2 rig and the Low Velocity Friction Apparatus. The paper also considers examples of the broader technical challenges posed by the latest ATF specifications in terms of more stringent oxidation, wear, extreme pressure, friction durability, torque capacity and anti-corrosion requirements, and compares the performance of the new friction durable ATF technology with other commercially available ATFs in some of these areas.

The fluid friction durability performance offered by this new additive technology is applicable in a variety of automatic transmission hardware, e.g. wet starting clutches, torque converter clutches, dual clutch transmissions and the latest generation six-, seven- and eight-speed step type automatic transmissions.

1. Introduction

The majority of automobile manufacturers are investigating the potential fuel economy benefits offered by employing lower viscosity ATFs so whereas previous generations of ATFs had a 100℃ Kinematic Viscosity (KV100℃) in the range of 7.0 to 8.0 mm^2/s, the new generation of ATFs, as specified in the General Motors DEXRON® VI ATF service-fill specification for example, typically have a fresh oil KV100℃ between 5.4 and 6.4 mm^2/s. This ATF formulation style offers potential fuel economy benefits because the lower viscosity fluids reduce churning (or spin) energy losses in the transmission, however the extent to which this can be measured depends on the test protocol and specifically the temperature range used in fuel economy testing. In most testing, the magnitude of the fuel economy benefit is roughly equivalent to the precision of the test being used to measure it, so careful test operation, statistical design of experiments and numerical analysis of the results are necessary (Box et al, 1975).

The use of lower viscosity ATFs can however pose significant challenges for the transmission hardware, especially with respect to pump losses and gear and bearing durability. Lower viscosity fluids leak more easily through pumps and seals and usually result in thinner protective films for bearings and gears unless the fluid design is specifically altered to compensate for the drop in Kinematic Viscosity. In addition, higher quality base oils may be needed for the lower viscosity fluids to ensure their robustness with respect to volatility, which affects oil volume within the transmission during operating life.

In parallel with the introduction of this low viscosity ATF formulation style, most automobile manufacturers have moved to new AT hardware designs to further enhance fuel economy. Newer ATs on the passenger car market have incorporated additional gears, e.g., six-, seven-, and eight-speeds, and start-up devices, e.g. wet starting clutches in place of conventional torque converter designs. The additional shifting energy associated with introducing a higher number of gears into the transmission can affect transmission durability, particularly with respect to the clutch packs (friction plates), and the ATF itself. In addition, new AT hardware designs typically offer smaller sumps that allow less fluid volume and less time in the sump for the ATF to release air and reduce foam. The combination of new hardware and a smaller volume of ATF in the transmission, requires an increased level of additive performance.

Many ATFs contain additive technologies which were developed over a decade ago, designed well before the release of currently manufactured AT hardware and for the reasons outlined above, the optimum performance additive and fluid design for the new step-AT hardware may require a significant performance increase over existing commercial ATFs. Three key ATF performance areas, with particular emphasis on the requirements of the Asian AT market, are discussed here: Friction durability in the shifting clutches and the torque converter, anti-wear and extreme pressure capacity, and anti-rust properties. The use of higher quality base oils and lower viscosity ATFs can offer significant oxidation and viscometric performance benefits, so less advancement of additive technology may be needed in these two performance areas.

2. Experimental Methods

This paper reports the evaluation of a new six-speed ATF additive technology using performance tests common to Asian passenger car original equipment manufacturers (OEMs). Each OEM has a unique set of ATF qualification tests, each demanding different additive requirements, however there is enough regional similarity of test rigs and procedures (specified by organizations such as JASO, CEC, ASTM, etc) to allow definition of a generic Asian six-speed ATF profile, which would be different both in test performance and additive design from either of the corresponding optimum European or North American six-speed ATFs. The data reported here compares the new Asian step-AT additive technology and selected commercially available ATFs taken from the Asian market, in terms of friction durability, torque capacity, extreme pressure (EP), wear and corrosion (rust) performance.

3. Results

Table 1 contains a limited viscometric and elemental profile of selected Asian factory-fill ATFs, coded as ATF-A to ATF-E. ATF-D is the most representative of the typical torque capacity offered by low viscosity Asian ATFs, and will be used for such comparisons later in the text.

Table 1: Select chemical and physical properties of ATFs taken from the Asian market. Listed are Kinematic Viscosity at 100℃ (ASTM D445), Brookfield Viscosity at -40℃ (BV-40, ASTM D2893), Phosphorus and Nitrogen levels and Total Acid Number (TAN, ASTM D664).

	KV100	BV at -40℃	Phosphorus	Nitrogen	TAN
	mm^2/s	mPa.s	µg/g	µg/g	mgKOH/g
ATF-A	7.3	17,600	282	2,221	1.7
ATF-B	7.4	12,150	285	2,296	2.2
ATF-C	7.3	16,260	219	1,553	1.4
ATF-D	5.4	9,320	298	1,980	1.6
ATF-E	6.0	10,120	180	1,450	0.6

The new friction durable additive technology developed by this laboratory is shown hereafter with the fluid code ATF-6. The ATF-6 fluid is formulated using conventional mineral oil only, and has a Kinematic Viscosity at 100℃ of 5.5 mm^2/s and a -40℃ Brookfield Viscosity of < 10,000 mPa.s.

Torque capacity and friction durability

The JASO M348 (2002) SAE Number 2 procedure using NW-461E friction material evaluates torque capacity (μ_t) and shifting clutch friction durability over 5000 cycles (43 hours), and forms a central part of the current JASO M315 ATF specification.

Figures 1(a) and 1(b) show a comparison of torque capacity μ_t and shifting clutch (μ_0/μ_D) durability performance for ATF-6 and ATF-D, measured by JASO M348. While the ATF-D fluid displays a continuing drop in torque capacity with test time (ca.15% over 5000 cycles), ATF-6 offers an equivalent torque level but with more stable torque capacity, Figure 1(a). Both fluids show broadly comparable shifting clutch anti-shudder durability as measured by friction coefficient ratio ($\mu_0/\mu_{D,}$), using this method, Figure 1(b).

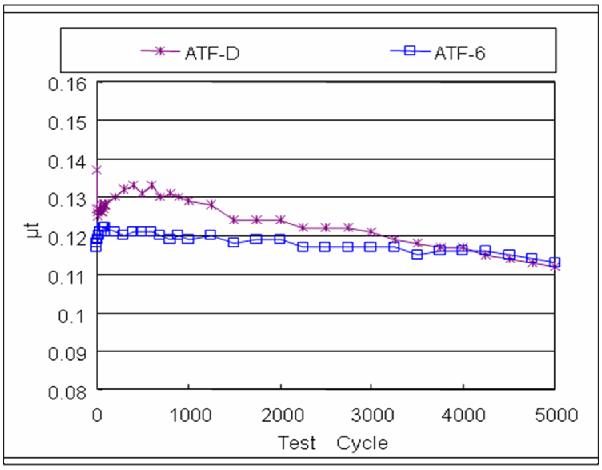

Figure 1(a): JASO M348 (2002) SAE Number 2 performance of ATF-6 and ATF-D. Torque capacity as measured by friction coefficient (μ_t) is shown per test cycle

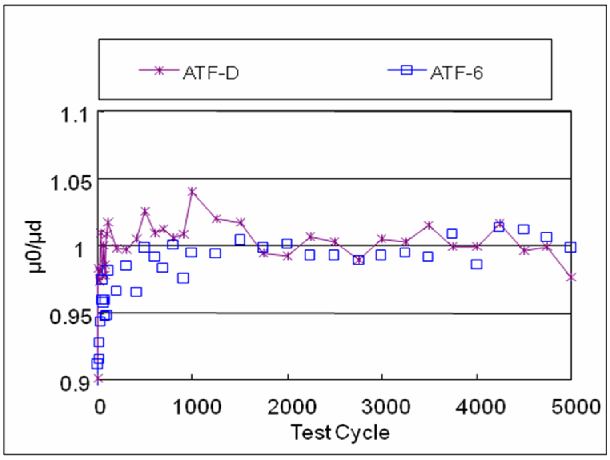

Figure 1(b): JASO M348 (2002) SAE Number 2 performance of ATF-6 and ATF-D. Shifting clutch anti-shudder durability as measured by friction coefficient ratio (μ_0/μ_D) is shown as a function of test cycles

The JASO M349 Low Velocity Friction Apparatus (LVFA) test measures friction in the low speed (0-300 rpm) regime, which is the most relevant for shift start-up devices. The coefficient of friction level μ, is measured as a function of relative speed (rpm, v), time (test hours), temperature (measured in the sump) and the plate friction measurement method (sweep or discrete-step mode).

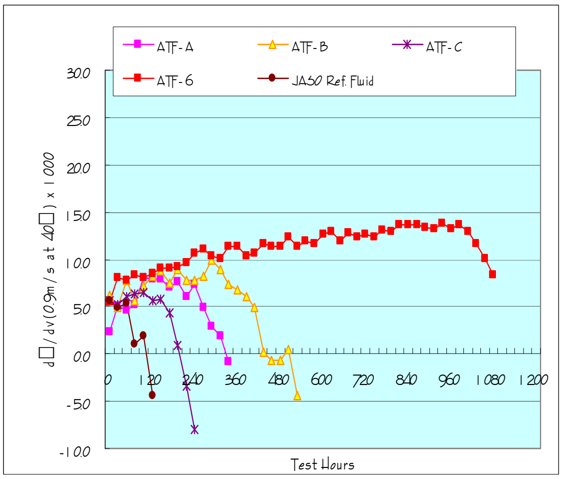

Figure 2(a): 40℃ LVFA durability of the 0.9 m/s (150 rpm) slope as a function of test hours

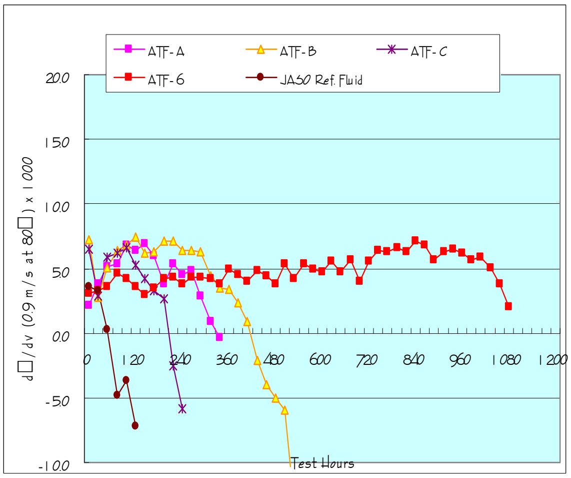

Figure 2(b): 80℃ LVFA durability of the 0.9 m/s (150 rpm) slope as a function of test hours

The number of test hours required for the slope of either the 40℃ or 80℃ μ-v curve to become negative, at the 150 rpm (0.9 m/s) speed point, is the standard JASO definition of fluid failure (friction durability lifetime). Note that JASO friction durability is defined in terms only of μ-v slope, not friction level, so fluids with steadily dropping low speed friction levels may appear to be durable. This is a very important consideration in AT applications because significant reductions in torque capacity may challenge the safety factors of the transmission calibration. Since field vehicle shudder investigations frequently find improper friction levels and/or slope in their “root cause” analysis, a more useful measure of friction system robustness is to inspect the entire μ-v curve as a function of test time and sump temperature.

Figures 2(a) and 2(b) report friction durability lifetimes as defined by the JASO M349 method for several of the ATFs shown in Table 1, compared with ATF-6. Figure 2(a) shows 150 rpm (0.9 m/s) slope durability at 40℃. Figure 2(b) shows data from the 80℃ testing. Among the fluids listed in Figures 2, ATF-B is known by this laboratory to have the longest LVFA durability of any ATF in Table 1, at approximately 450 hours. As shown in Figure 2(a), ATF-6 easily reaches the 1000-hour durability mark, representing a two-fold increase over ATF-B and a 12-fold improvement over the industry (JASO) reference fluid Toyota T-III.

Additional performance parameters

As previously noted, it is not possible to judge quality of an ATF in terms of its friction performance alone and the use of older additive technologies in conjunction with newer transmission designs brings additional challenges to the ATF formulator. EP and corrosion properties pose a particular challenge because components offering EP, friction durability and corrosion performance all have a tendency to migrate to (and adsorb onto) either a steel or composite (friction material) surfaces. Usually therefore a balance of surface-active components is required to achieve acceptable overall ATF performance; this need for balance usually limits significant performance breakthroughs.

Table 2: ASTM D665A anti-rust performance

Fluid	ASTM D665A
ATF-A	Fail
ATF-B	Fail
ATF-C	Fail
ATF-D	Fail
ATF-6	Pass

Anti-rust performance becomes more important as fluid viscosity and lubricating films get thinner. The ASTM D665A test method, also used in JASO specifications, is an industry standard procedure for measuring anti-rust performance. Many Asian ATFs even at the higher 7.2 mm^2/s viscosity already have well-known weakness in this performance area. Table 2 lists the ASTM D665A anti-rust performance of the fluids listed in Table 1.

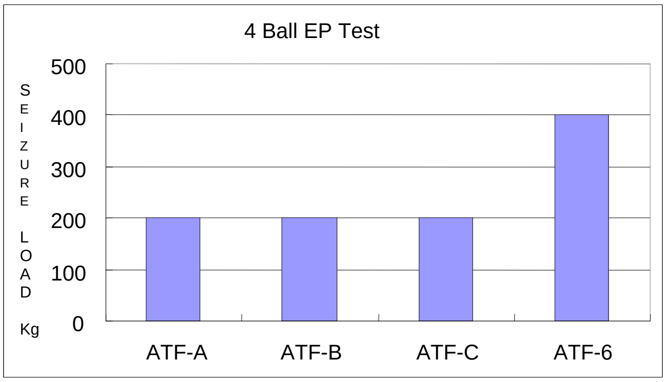

Figure 3(a): 4-ball EP test results by ASTM D 2783

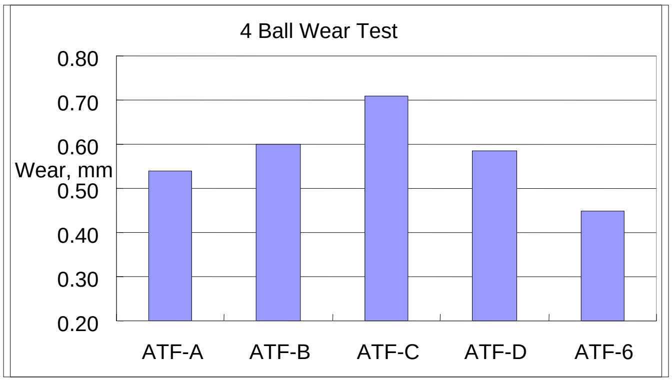

Figure 3(b): 4-ball wear test results by ASTM D 2266

Industry standard bench tests can also be used to determine the EP and anti-wear performance of ATFs and Figures 3(a) and 3(b) show results from the 4-ball EP (ASTM D 2783) and 4-ball wear (ASTM D 2266) tests, which are standard industry test procedures for the Asian region. In the 4-ball EP test, the highest seizure load (400 kg) is found with the new friction durable fluid ATF-6 where the EP benefit of ATF 6 over the comparison fluids is significant beyond a 95% confidence level.

Conclusions

In summary, this paper reports the development of a mineral oil-based Asian-focused ATF that offers over 1000 hours of LVFA friction durability, which is twice the performance of any current commercial Asian ATF, with comparable torque capacity. Anti-rust and EP performance have also been shown to be well above that of other commercially available ATFs in the region, suggesting that poor EP or anti-rust performance is not necessarily a consequence of fluids with enhanced friction-durability. In our opinion, the ATF-6 fluid represents a qualitatively new level of friction durability which may enable successful development of new types of transmission hardware or allow new transmission calibration regimes.

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UDK	ključne riječi	key words
621.892:621.83.069.2	ulje za automatske prijenosnike specifikacije Dexron VI	ATF fluid Dexron VI specification
621.83.069.2	automatski prijenosnici	automatic transmission
665.764.038.5	aditivi za ATF ulja automatskih prijenosnika	additive for ATF fluids
539.62	anti-frikcijska svojstva	anti-shudder performance
539.61	svojstva zaštićenosti od trošenja	anti-wear properties

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