

INVESTIGATION OF FRICTION COEFFICIENTS OF ADDITIVATED ENGINE LUBRICANTS IN FALEX TESTER

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Abstract: *The paper deals with experimental mechanics in the field of fluid lubricants, investigating frictional characteristics of engine oils using experimental tests on a pin and vee block test machine (Falex). The test is standardized according to ASTM D3233 and represents a relevant and rapid measurement of coefficients of friction in a tribometer. Seven engine oils were tested on the same loading-time procedure being analyzed the coefficients of friction according to manufacturer and additivation.*

Key words: *engine lubricants, friction coefficient, pin and vee block test.*

1. Introduction

Recently, ambitious emission targets imposed new demands on engine lubricants (reduction of viscosity, use of friction modifiers, control of oil thickening by detergents and dispersants) in order to limit as much as possible friction losses.

Compatibility matters impose difficult and expensive alternatives on formulation of additive package - the additives should not impede their functions one to each other; moreover, the use of after treatment devices such as diesel particulate filters, three way catalyst, NO_x adsorbers or selective catalytic reduction systems limited sulphur, phosphorous and sulfated ash content in lubricants.

Engine development in the next decades generates new durability challenges: the solutions of engine downsizing, turbocharging or direct injection lead to higher stress at the same load, while fuel economy requests lower viscosity oils and

enhanced additive packages [1].

The engine lubricants are formulated to perform a range of tasks:

- to prevent against wear the surfaces in boundary lubrication by additivation;
- to avoid direct contact of engine parts by keeping a continuous film in hydrodynamic lubrication;
- to prevent corrosion due to degradation or contamination.

Engine friction losses are evaluated at 10-12% of fuel combustion energy [3] so at the global scale any friction reduction saves fuel resources and avoids green house effect.

For vehicle owner the friction reduction lowers the costs of maintenance operations and increases the overall reliability.

The friction loss depends strongly on tribological properties of the lubricants. In order to evaluate different compositions of base oils or formulated oils a reliable research instrument is the accurate measurement of friction coefficient in a tribometer.

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The objective of this paper is to investigate in a special purpose tester the friction coefficients of seven commercial engine lubricants and to compare friction reduction capability, as well as the effect of two aftermarket additives, a friction modifier and a detergent-dispersant additive.

2. Testing Methods

The principle of operation of lubricant testers is known for many years and they were kept unchanged due to their high capacity of reproduction of loads, wear and failure conditions. Although the real life engine loads were, in a certain extent, different from tester loads, the method proved to be reliable for comparison of different lubricant compositions.

The tester can simulate different regimes of lubrication which depend on load, speed, temperature, geometry of the bearing surfaces, but also on lubricant properties, mainly viscosity and density.

The literature indicates in function of lubrication oil film thickness, a four area curve, known also as Stribeck curve, which characterizes four different regimes of lubrication [4-5]: boundary lubrication (BL) is the lubrication when surfaces in relative motion are mostly in contact, mixed lubrication (ML) is when the surfaces are partly in contact and partly separated, elasto-hydrodynamic lubrication (EHL) is the one having a very thin separation oil film, in which the elastic deformation of surface and oil viscosity are important, and finally hydrodynamic lubrication (HL) is that lubrication in which the relative motion of the sliding surfaces maintains a continuous fluid film separating the surfaces.

2.1. Tribometer

The pin and vee block method is known also as Falex method and assesses the

lubricant behavior typically in industrial applications for measurement of extreme pressure [7], wear properties of fluid lubricants [8], wear and load carrying capacity of solid film lubricants [9].

The friction device is described in Figure 1. A rotating pin (journal) fixed with a locking fuse rotates at constant speed against two vee blocks, all immersed in 60 mL of tested lubricant.

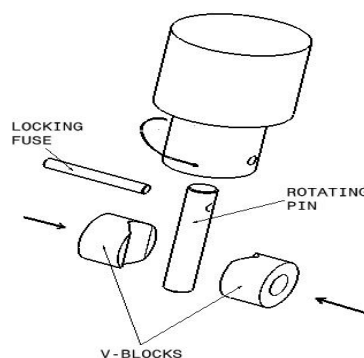


Fig. 1. *Falex pin and vee block device*

The contact between the pin diameter and the vee blocks is linear along four lines and it appears when a load is applied through a mechanical gauge by means of a ratchet wheel and eccentric arm.

2.2. Lubricants and Additives

The lubricants supposed to tests were seven commercial engine lubricants, having the same SAE class of viscosity, 10W40, marked with M1...M7, the brand names being kept anonymously.

The lubricant densities and viscosities indicated by producers are presented in Table 1.

Similarly the after-market additives were marked A1 and A2.

The additive A1 is a detergent-dispersant which dissolves sludge and lacquer formers, the residues being brought into suspension. The indicated concentration in lubricant is 5% (v/v).

Physical properties of engine lubricants

Table 1

Type	M1	M2	M3	M4	M5	M6	M7
Viscosity (40°C) [mm ² /s]	96.4	96.8	93.04	97	94	102.5	85
Density [kg/m ³]	868	873.6	863	874	868	862	871

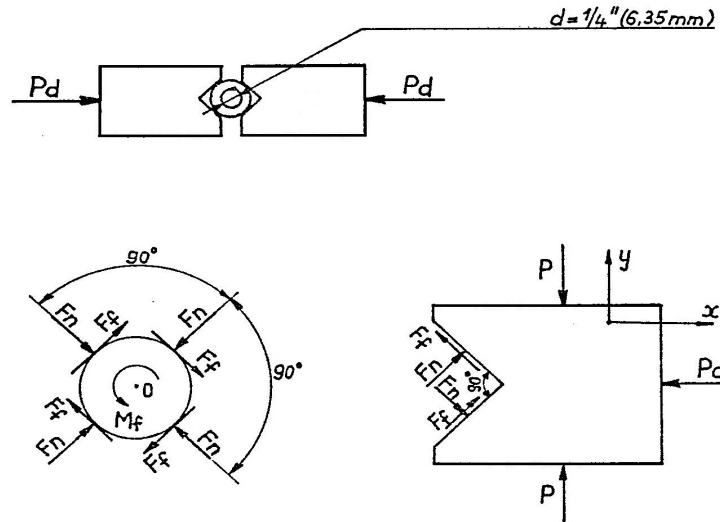


Fig. 2. Scheme for the calculation of friction coefficient [4]

The additive A2 is a friction modifier which actuates upon surfaces making them slippery, by depositing a thin layer of long molecules with polar groups which are attached to metal surfaces. The treatment is efficient especially in BL lubrication regime with surfaces still in contact. The indicated concentration in lubricant is 5-10% (v/v).

2.3. Testing Procedure and Calculus

The tester is driven at constant speed (290 rpm) when external load is applied on the vee blocks, all parts being immersed in lubricant bath. The tangential friction force, F_f , produces friction torque, M_f , and the coefficient of friction between pin and vee blocks is calculated according to equations of force and torque conservation, as illustrated in Figure 2.

Applying the torque conservation upon the pin, it yields the following Equations:

$$\sum M_O = 0, M_f - 4F_f \cdot \frac{d}{2} = 0,$$

$$F_f = \frac{M_f}{2d}, \quad (1)$$

where d - pin diameter.

Applying the force conservation on x direction upon the vee block, it yields the following Equations (2):

$$\sum F_x = 0, -P_d + 2F_n \cdot \cos 45^\circ = 0,$$

$$F_n = \frac{P_d}{2 \cos 45^\circ}, \quad (2)$$

with P_d - direct load, F_n - normal force.

Finally, the friction coefficient, μ , is calculated with formula (3):

$$\mu = \frac{F_f}{F_n} = \frac{\frac{M_f}{2d}}{\frac{P_d}{2 \cos 45^\circ}} = 2.9724 \frac{M_f}{P_d}, \quad (3)$$

with M_f expressed in inch-pounds and P_d expressed in pounds-force.

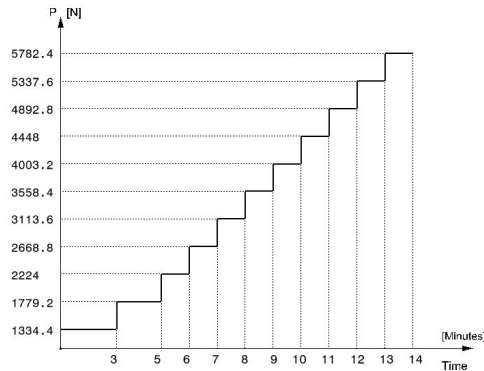


Fig. 3. Load versus time - testing program

The tribological testing starts with a 15 minutes run-in test, adapted from standard [7], to smoothen the vee block surfaces. The load is applied in gradual ascending steps, as described in Figure 3, which were chosen considering similar tests performed in [6] for commercial engine oils. Each test was triplicated for each lubricant.

3. Results and Discussions

3.1. Tests for Pure Lubricants

The calculations of the coefficients of friction for pure (non-additivated) engine lubricants were performed for the same loads and are illustrated in Figure 4, having load expressed in Newtons and coefficient of friction being dimensionless [2]. The trend lines were plotted using third order polynomial regression. The variation of friction coefficients has approximately the same profile, decreasing with increasing load up to inflexion point, then increasing with load. The inflexion point represents on Stribeck curve [5] the transition between two lubrication regimes, from EHL to ML. The position of the inflexion point is also variable from one oil to another, due to the variation in viscosity and density.

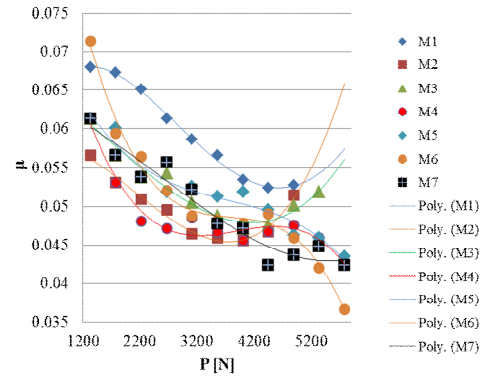


Fig. 4. Friction coefficients versus load

A factor of merit is the positioning of the inflexion point at highest loads (ex. M5 and M6) showing a high resistance at extreme pressures. Regarding the coefficients of friction, excepting the behavior of lubricant M1 which have higher values on the whole range of loads, the rest of lubricants have values in relatively broad intervals, in the range 0.043-0.062.

3.2. Tests for Additivated Lubricants

The detergent-dispersant additive A1 has a fair reduction of friction coefficient for most of seven oils. The reduction is higher for 5% concentration as it can be seen in Figure 5, being chosen as representative M6 oil; the graphics also proves that extra additivation from 5% to 10% is harmful.

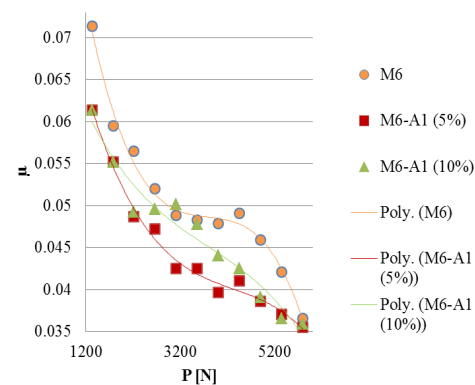


Fig. 5. Coefficients of friction versus load for additivated (A1) M6 engine lubricant

The friction modifier additive A2 has a significant reduction of friction coefficient for all seven oils. The reduction is higher for 5% concentration as it can be seen in Figure 6, being chosen as representative M7 oil; the graphics also prove that extra additivation from 5% to 10% is not so beneficial. Comparing the friction reduction of 5%A1 with that of 5%A2, in terms of area magnitude between curves, it is obvious that friction modifier A2 is more efficient.

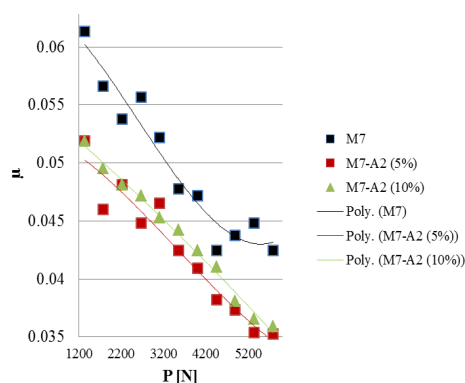


Fig. 6. Coefficients of friction versus load for additivated (A2) M7 engine lubricant

It is important to compare also the wear produced by similar test upon pins. The visual inspections of the specimens are seen in Figures 7 and 8.

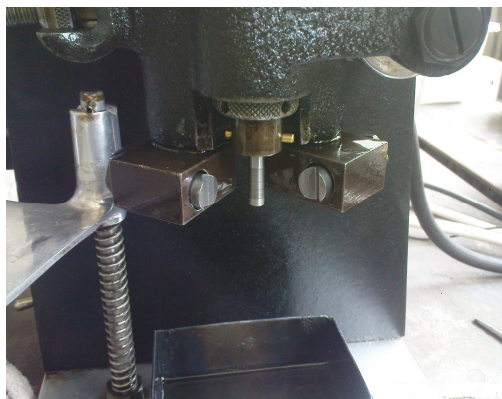


Fig. 7. Pin at the end of the friction test

Each test is provided with brand new set of pin, vee blocks and locking fuse, so the wear trails can be easily attributed.



Fig. 8. Scuffed pins and vee-blocks

The pin from the right side of figure 8 which supported A2 additivation indicates less wear than the pin from left side which supported A1 additivation, showing that the mechanism of attaching polar layer was effective.

4. Conclusions

The investigation of seven engine lubricants belonging to the same class of viscosity which were tested at extreme pressure in Falex tribometer revealed the following aspects:

- the friction coefficients of pure commercial lubricants varies within 0.01-0.02 at a given load, showing that the lubricant dispersion is relatively high and it could still be optimised the fit between engine and its lubricant;
- the additivation with A1 detergent-dispersant additive has a collateral effect of decreasing the coefficient of friction with a mean value of 0.004;
- the additivation with A2 friction modifier is efficient, decreasing the coefficient of friction with a mean value of 0.008.

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