

Fundamental Understanding of Antiwear Mechanisms in Real-World Applications: Part 1

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ABSTRACT

Increasing pressure to deliver vehicle fuel efficiency without compromising engine durability places significant demands on engine lubricants. The antiwear capability of the formulation is extremely important as wear on engine parts can lead to engine inefficiency. The rapidly advancing and diversifying array of engine architectures creates ever more arduous conditions under which lubricant additives must perform. The evolution of engine design brings with it the propensity for a variety of wear mechanisms to occur. This paper reports research conducted to rapidly collect key information from which to begin to conceive the design of better screening technologies. An exploration of wear mechanisms using simple bench-top experiments was conducted using a variety of lubricants. A lab based oil-aging technique was used to attempt to create an oil sample with wear properties mimicking those of real engine drains. Engine testing was conducted in a novel manner to facilitate fundamental knowledge generation and leads to the conclusion that a deeper understanding of the specific antiwear mechanism at play is essential. From these engine tests, a hypothesis is made describing the requirements of successful anti-wear additive systems.

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INTRODUCTION

As the automotive industry advances deeper into the era of efficiency, lubricants are required to play an increasingly important and complex role. Advances in engine hardware technologies push tribological systems further than ever before. Efficiency must be achieved, but without compromise, ensuring a life cycle benefit from the engineering system. Maintaining and ensuring the durability of engine hardware components is essential for efficient operation of the engineering system as a whole.

The diversity of available engine architectures means there are a wide range of operating conditions and environments under which lubricant additive systems need to perform. A deep and modernized understanding of these conditions and how they influence wear is required for successful additive package formulation.

So called 'screening tests' are an integral part of the molecular research and development process. Structure-performance relationships explored by these tests shape the final molecule and link directly to the final field performance of the fluid. It is therefore essential that the screening process be robust and founded with good tribological consideration of the key drivers that relate to real-world effects.

Wear Testing Background

Laboratory based research on any lubricant property must be founded on the specific knowledge of the intended application. Experimental testing used in the development or screening stages of lubricant development must be designed to have relevance to the real-world application. While a screener-test must bear correlation to performance in the final application, it should do this as simply as possible and have the following attributes [1]:

- Tests should be rapid and inexpensive to perform.
- Test specimens should be small and simple, costing little to fabricate, and allowing the use of small quantities of new or developed materials.
- Test results should demonstrate a high degree of repeatability and reproducibility, lending themselves to standardization wherever possible.
- The test method should be easy to perform, requiring little investment in operator training and minimal subjectivity of the operator when making measurements of processing results.

This review by Blau concludes that it may not be necessary to duplicate every aspect of a specific application to effect a useful screening tool, it does however suggest it is absolutely necessary to identify the key mechanical, thermal and chemical variables if laboratory results are to be useful. Special mention is made that the state of contamination in the lubricant or environment should also be duplicated.

ASTM International has developed a wide variety of ‘off-the shelf’ standardized wear tests for specific applications. Blau et al. list nearly 20 standards with accompanying case studies of their application to solve industrial problems [2]. Perhaps of most frequent use in automotive lubricant related tribology laboratories across the globe is the ASTM G133 procedure: ‘The Standard Method for Linearly Reciprocating Ball-on-Flat Sliding Wear’ [3]. In this procedure a ball is reciprocated against a flat surface and test loads and speeds are to be determined by the severity of the proposed application. The geometries employed here, whilst deviating from those specifically found in the engine, do allow adherence to the attributes required for a basic screener-test listed above. A similar geometry is employed in the ASTM D6079 procedure, the standard method for evaluating lubricity of diesel fuels by the High Frequency Reciprocating Rig (HFRR) [4]. Despite the fact that the machine originally found its niche in evaluating the lubricity of diesel fuels, modifications to the procedure have made it popular for research pertaining to the automotive lubricants industry as it approximates to the overarching ASTM G133 standard.

While it is widely accepted that data produced from any bench-top ‘screener test’ should inherently be accompanied with a variety of caveats, the role of the test is extremely important. These first order experiments often function as a stage gate in the process of research and are frequently used to guide future activities. So while their approach is, and has to be, overly simplistic, their contribution is perhaps the most important in the developmental stages of research. With this in mind, the aim of the research reported in this paper is to investigate Antiwear mechanisms as they relate to different engine architectures and lubricants and propose key drivers for inclusion in screener experiments specifically designed to target certain wear mechanisms. Research was also conducted to investigate the real-world mechanisms of action of a novel Antiwear formulation using bespoke engine testing.

METHOD

Method 1 - Benchtop Wear

To gain basic understanding of drivers for wear, a variety of engine oils were selected for basic tribological testing. A HFRR was used to create standardized conditions under which oils could be evaluated equally (Table 1).

After testing, the ball specimen was removed from the machine and thoroughly rinsed with solvents. It was then chemically cleaned using a solution of ethylenediaminetetraacetic acid using a procedure developed by Topolovec-Miklozic et al. [5]. It was found by the authors, and confirmed by other researchers, that this approach is necessary to ensure accurate determination of wear when using light imaging analyses [6]. Following chemical cleaning, wear volume was determined using a Zygo NewView™ 7300 3D Optical Profiler.

Table 1. HFRR test conditions for basic screening tests to develop understanding of key wear mechanism drivers.

Stroke	1 mm
Frequency	20 Hz
Lubrication	Fully flooded
Temperature	Linear ramp 40 °C to 120 °C
Duration	1 Hour
Load	1.9 N
Reciprocating Specimen	6mm diameter ball, AISI 52100 steel, 650-670HV(ISO 6507/1), <0.05µm Ra
Stationary Specimen	Disc, AISI 52100 steel, 190-210HV, <0.02 µm Ra

Lubricants

A variety of lubricants were selected for evaluation using the ball-on-flat test. Lubricants selection was designed to scope the corners of the passenger car engine oil landscape, and to add understanding to associated wear mechanism drivers (Table 2).

To investigate the mechanistic driver of wear in the ‘Drain’ sample, the end of test drain oil from a sequence IVA engine test was subjected to centrifugation to separate liquid and solids in a procedure documented by Uy et al. [7]. This oil is defined by the descriptor, ‘Supernatant’.

To investigate the effect of oxidation on wear mechanism, the ‘Fresh’ sample was submitted for Romaszewski Oil Bench Oxidation (ROBO) testing. This is an ASTM standard bench-top test designed to simulate aging in the sequence IIIG engine test method (ASTM D7528-13). During this procedure, candidate oil is treated with iron ferrocene and heated for 40Hrs at 170C with air and nitrogen dioxide flowing under a vacuum. The oil subject to this procedure is defined by the descriptor, ‘ROBO’ in table 2.

To allow for high level observations to be made between different engine architectures, Port Fuel Injected (PFI), Gasoline Direct Injected (GDI) and Turbo Diesel (TDI) drains were tested. These oils were all subjected to different real-world operating conditions. This piece of work was done to rapidly scope the potential differences that might exist between oils sampled from different applications. In order to develop a wear screener it is necessary first to understand what potential wear drivers might exist in the real-world, and how different they are from each other. To this, despite the fact that the samples were all collected from different engines operating under different conditions, they were all tested using the same protocol to provide a basis for meaningful observation to be made. While these oils exhibited different viscosities due to the vastly different engine architectures they serve, testing was designed to operate in the boundary lubrication regime only, where viscometric properties are not a primary concern. This selection of lubricants merely samples the infinite range of passenger car drains that exist in the real-world today and is in no way definitive. This piece of research therefore was not designed to provide basis for specific