Metropolia University of Applied Sciences Helsinki, Finland

Degree Program (BEng) in Automotive Engineering

Major in Automotive Electronics Engineering

Research Title: Extreme Pressure Engine Oil Lubricant Comparison

Abstract

Background & Objective

This research was contracted to Metropolia University of Applied Sciences by MW Steel Oy, a Finnish company specialized in the design and build of race engines and high-performance engine tuning.

Tribology is the science of interacting surfaces in relative motion, focusing on friction, wear, and lubrication. As this research concentrates on the tribological characteristics of next generation oil lubricants, it was our great pleasure and honor to have Dr. Pekka Salonen, President of the Finnish Tribology Association, as our mentor, supervisor, and approver for this research.

For the analytical findings and outcomes, several specialists of the oil industry, professional race engine-builders as well as engineers in tribology were interviewed, and their valuable input considered.

Surface tension resistance a.k.a. film strength is considered by many the single most important characteristic of any lubricant in terms of protection against engine wear provoked by metal-to-metal friction. As the share of unknown engine failures is in the rise, car manufacturers pay more attention to proper lubrification. Extended oil change intervals together with extreme temperature and pressure conditions set increasingly higher demands on oil lubricants.

In the absence of standardized methods or ratings to compare engine oil protection characteristics, the end-user's choice is commonly based on subjective opinions or hear-say with very few scientific facts behind them, affected by strong brands with large budget flashy marketing campaigns, the proof of which are endless blogs and debates in social media under the topic "best oil for your engine". Unfortunately, this phenomenon is also reflected in car maintenance and repair workshops as well as gas stations selling lubricants, who tend to promote specific brands for the very same reasons. Hence, the motivation for this research - to obtain a simple and clear-cut, easily understandable way of comparing engine oils with scientific substance based on tribological protection characteristics.

The primary function of an engine oil is to prevent wear and lubricate moving parts. Other functions include transfer of heat and the attraction of impurities. Vehicle manufacturers' extended maintenance intervals in modern engines of up to 50.000 km / 30.000 miles sets tough demands to long-life oils for cleansing capabilities to attract, break down and transfer impurities and dross to filtering systems. To meet these demands, cleansing additives such as detergents and dispersants have become more common in engine oil lubricants.

In race and highly tuned engines cleansing additives may have a negative impact on engine lubrication and protection, especially if they compromise the use of Extreme Pressure (EP) and Anti-Wear (AW) additives

designed specifically to improve film strength. Tribologically advanced next generation lubricants can provide both good film strength as well as extended oil change intervals.

To stay competitive, the tendency of large oil corporations to focus on volume products drives marginal producers to concentrate on quality rather than quantity. As cleansing additives are less costly than tribologically developed anti-wear (AW) and extreme-pressure (EP) compounds, volume products include more of the previous, i.e. cleansing additive packages at the expense of the latter, thus compromising on oil film strength. Smaller lubricant manufacturers seem to be keener on developing tribologically advanced oils, be it at higher cost.

A total of 40 lubricants were tested and analyzed in this research. For a statistically meaningful selection, several oils not represented in Finland were purchased from abroad.

The picture below illustrates some of the tested oil lubricants.

Figure 1: image of tested oils

Test Procedure

This research was conducted using a commercially available portable Timken-type load tester, developed by Henry Timken in 1935. The original Timken method has faced criticism originating from the load add-on principle of weights and human muscular intervention creating probable cause of result manipulation and biasing, which compromises the reliability of the results.

The tester used in this research was, therefore, modified and the loading process significantly improved with a unique purpose-built hydraulic auto-loading mechanism delivering a fully linear and constant load increase, which achieves a remarkable 5% mean value repeatability vs. the 30% accepted by the original Timken Method.

Figure 2: Commercial portable Timken device

Figure 3: Core of the testing method

Measurements and calculations

To determine the surface tension resistance a.k.a. film strength for each oil, the following measurements were carried out:

1. Scar Size / surface area (mm2) on Roller Bearing Test Block
2. Loading time (sec) until tripping point / disconnect of electric motor
3. Temperature (°C) at end of the load cycle
4. Price Quality Index (PQI) comparison

The PQI is derived by dividing the measured Film Strength (PSI) value with the lowest available liter/quart price (Euros) of the respective oil in Finland at the time of testing, and by multiplying it with a Constant. This comparison was made to facilitate end-user decisions considering available budget:

PQI = (FS / price) * C

For Scar size, the elliptical surface area A is derived from the following formula

$$A = \pi \cdot ab$$

where a and b represent the half axes of the ellipsoid.

By measuring the scar width (l) and length (h) you get:

$$A = \pi \cdot \left(\frac{l}{2}\right) \cdot \left(\frac{h}{2}\right)$$

from which the surface tension P can be derived from:

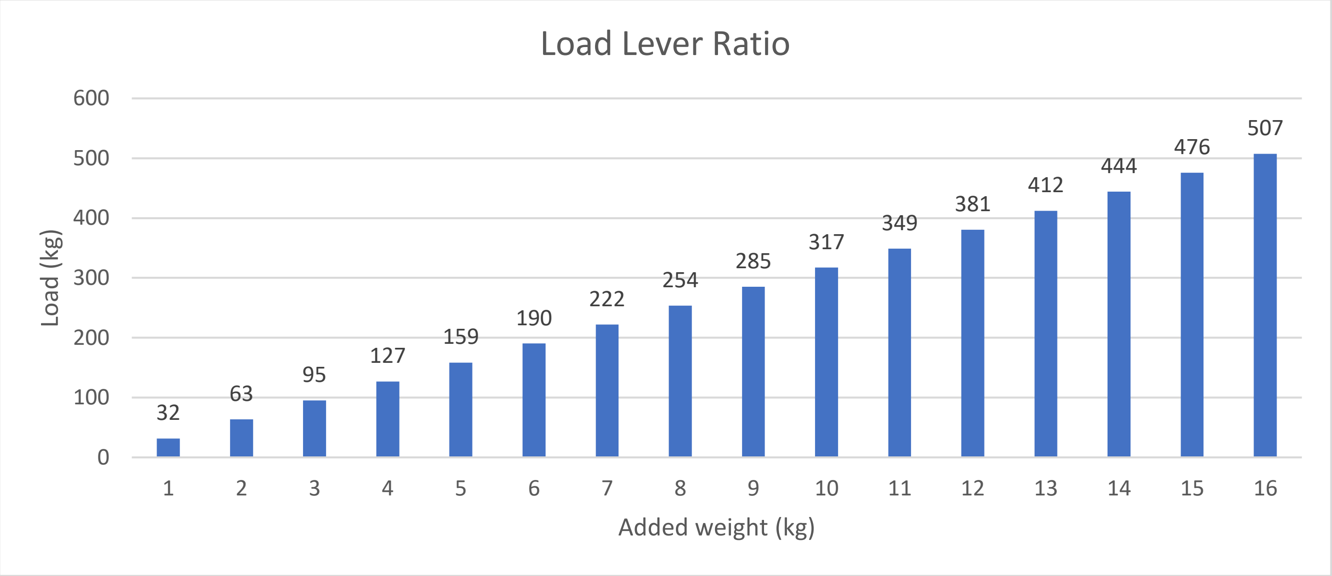
$$P = m/A$$

For deriving the final surface tension resistance or film strength, the mass is supplemented by the initial lever weight and multiplied by the lever ratio x:

$$P = \frac{(m+1) \cdot x}{A}$$

The chart below illustrates the linear increase of the lever mechanism load ratio. The additional mass increase was multiplied with a ratio of 1:31,71 for the lever weight-arm mechanism, which was needed to achieve the tripping point of the best performing oils

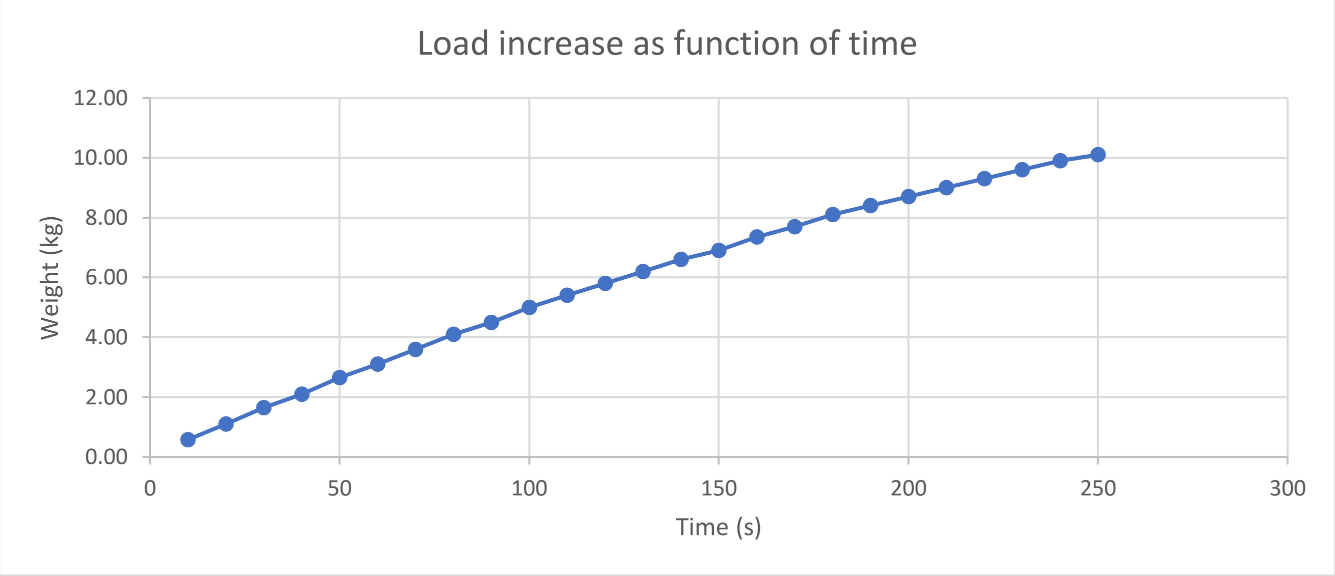
Chart: Load Lever ratio



A stable and constant test environment for engaging the test process was set an imperative pre-requisite. The tested lubricants were divided into two categories, namely "Street Oils" and "Track Oils" based on their viscosity values and/or manufacturer labeling, the latter representing typically high-end premium grades from the same manufacturer. Measurements were focused on surface tension resistance a.k.a film strength.

The criteria were meaningful repeatability, which was achieved by modifying the mechanical weight-based load increase mechanism to a constant and steady flow of liquid. By doing so, an identical load increase was achieved for all tested oils, according to chart 3, with the load curve representing a decreasing parable. The targeted repeatability level was achieved, in addition to eliminating any error factor by physical human intervention to the loading process.

Chart: Load increase as function of time



All measurements were performed during the same day. Each oil was numbered and listed. Testing was performed in numerical order and the load weight, time, final temperature, and scar size were recorded.

Each test was initiated by installing a clean outer bearing surface to the oil cup, and a clean roller bearing (hereafter: “test block”) which represented the main surfaces under wear.

Before commencing testing, each oil was pre-heated to 110°C / 230°F and left to cool down until reaching 100°C / 212°F, at which point the electric test motor was engaged. Loading was initiated at exactly three seconds from this point. During testing, audiovisual observations regarding oil friction and temperature behavior were carried out.

Increasing surface tension to the oil film’s breaking point causes the electrical motor to overload at which point it cannot any longer provide sufficient torque required by the friction level between the metal bearing surfaces. When this frictional force exceeded the electric motor’s torque limit, the motor was automatically disengaged (hereafter tripped) at which point the running time and temperature was recorded. At the end of the test the resulting scar length and width provoked in the test block was measured with a digital Maher Verner caliper and using a microscope for additional scar observations. Each oil was tested four times removing the highest and lowest value outliners from the calculation and by recording the average of the 2 remaining results in the final test results.

Picture: Archived test blocks

Repeatability

Meaningful repeatability was an imperative pre-requisite to start any testing activities. To achieve this the original commercial Timken test system was modified by improving the loading mechanism as well as the tribological characteristics of the lever weight-arm material. Appropriate mental orientation and systematic personal behavior during measurements were also scrutinized.

The loading mechanism was completely upgraded from physical weights to a more precise liquid-based drain to a recipient located at the far end of the lever weight arm, monitored by a digital scale. The weight arms were also modified from the original soft metal to a hardened and more load-resistant alloy.

The picture below illustrates a reference test block with several scars provoked by the same oil. The repeatability calculations were validated on a pair of reference test blocks with ten repeated scar and weight load measurements performed on each roller bearing using two oils with different surface tension characteristics. The result was < 5% error on repeatability, which met the set target criteria.

Picture 5: Reference Test Block with several scars from same oil

Test Results

The test results are reflected in the charts hereafter and depicted separately for Street and Track Oils in descending order. It is worth noting that regarding Film Strength, the single most important oil characteristic for engine protection and lubrication in this research, top oils in the Street category perform better than the weakest Track oils. Equally important to note is that the categorization provided by oil manufacturers in their bottle labels and marketing slogans is artificial and does not correlate with film strength.

Chart 5: Measured Film strength values (PSI) Street Oil Category

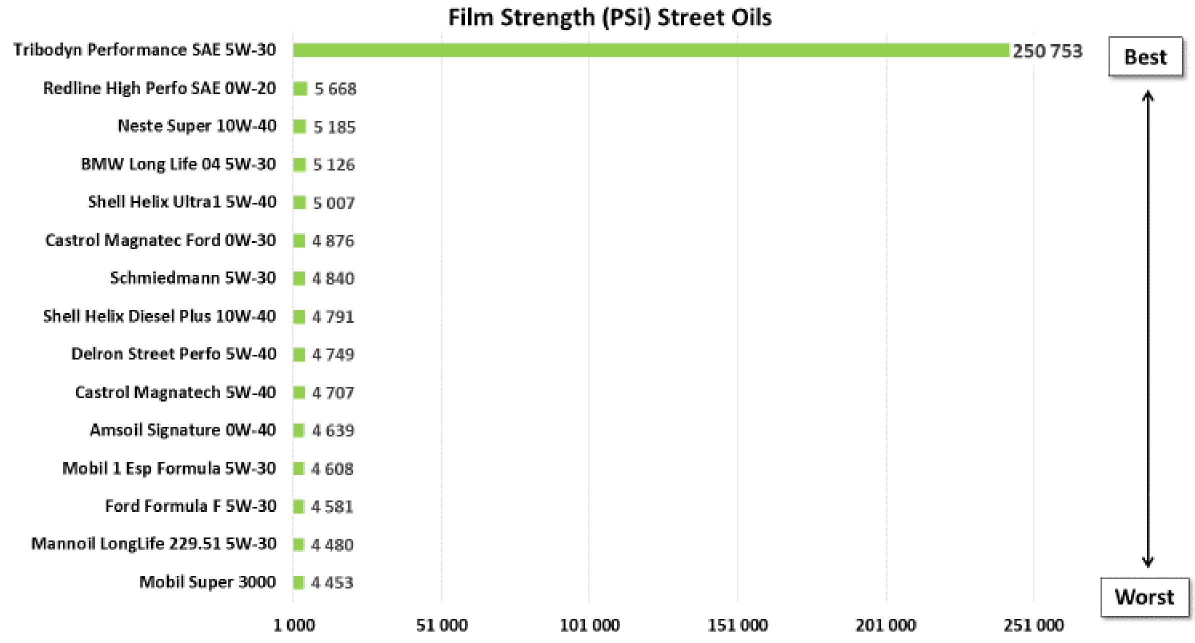


Chart 6: Measured Film strength values (PSI) Track Oil Category

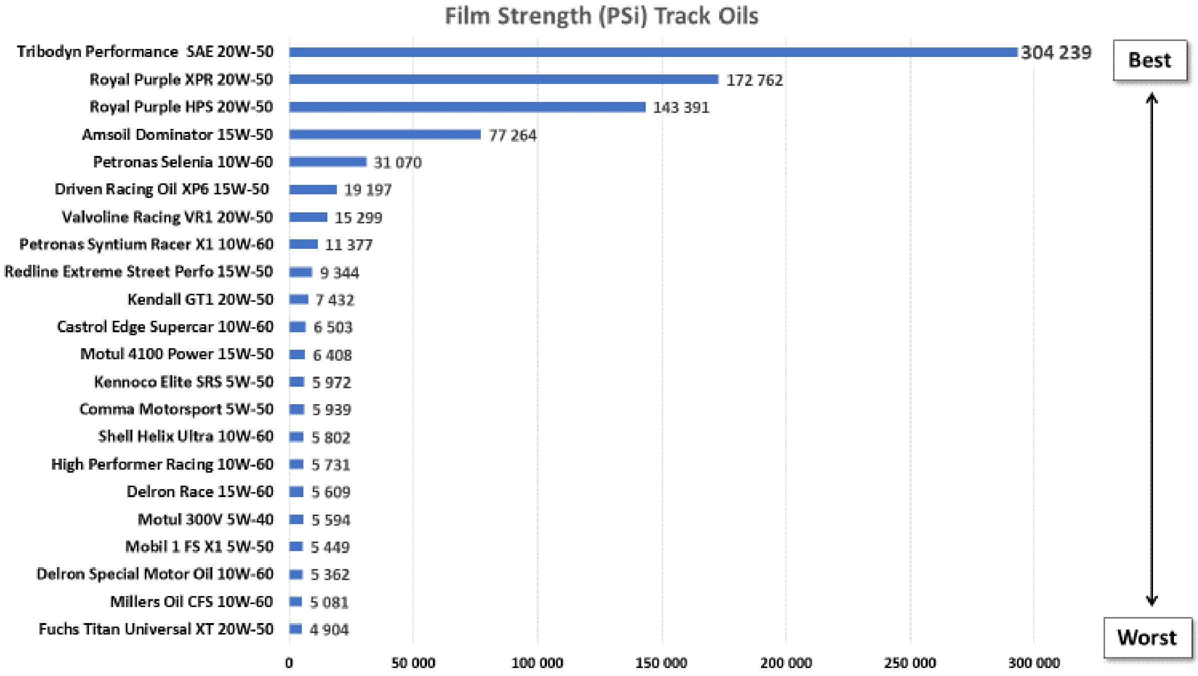


Chart 7: Measured Scar Sizes (mm^2) Street Oil Category

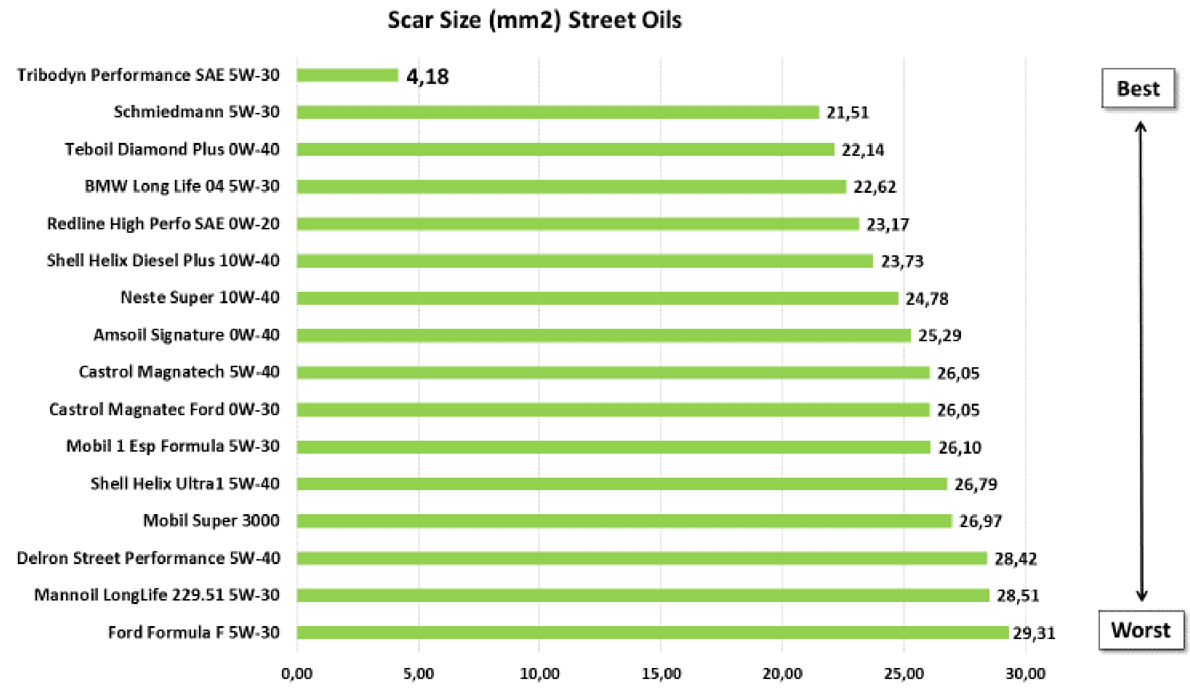


Chart 8: Measured Scar Sizes (mm^2) Track Oil Category

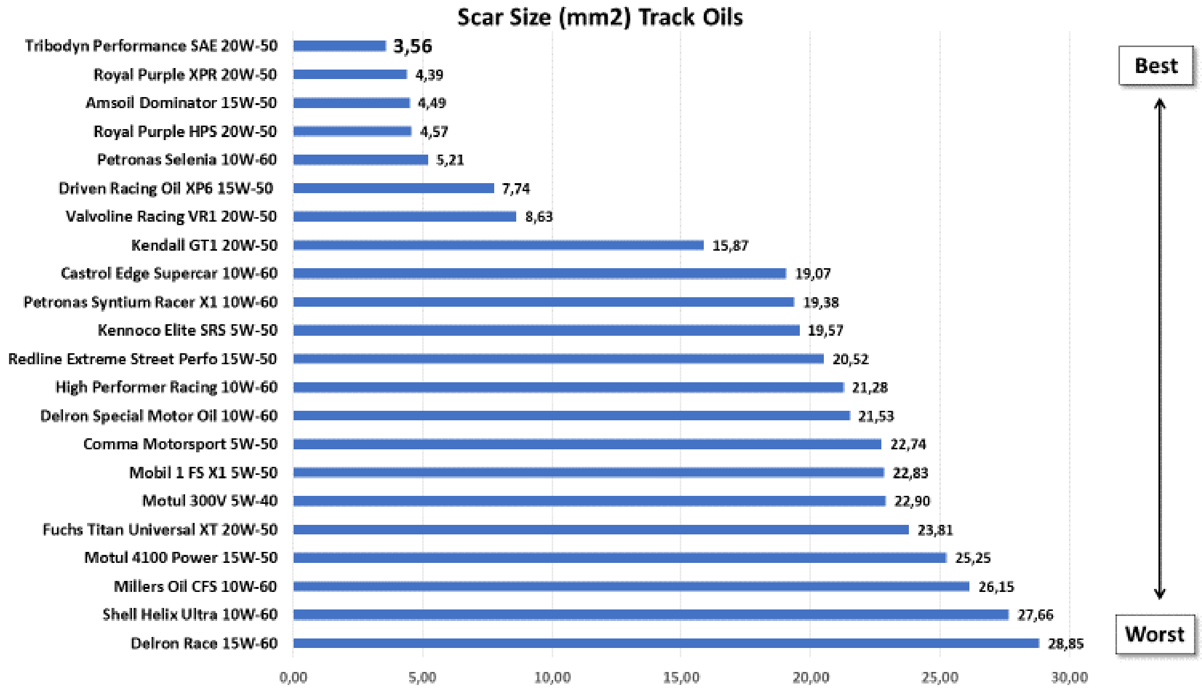


Chart 9: Measured Load Tripping Times (sec) Street Oil Category

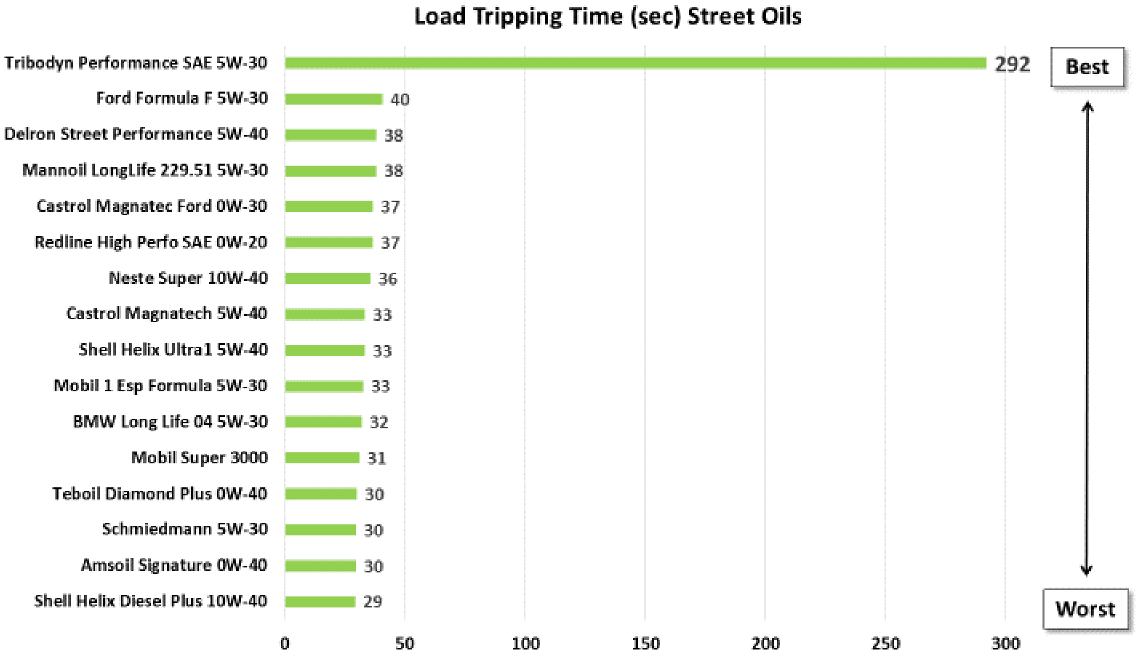


Chart 10: Measured Tripping Times (sec) Track Oil Category

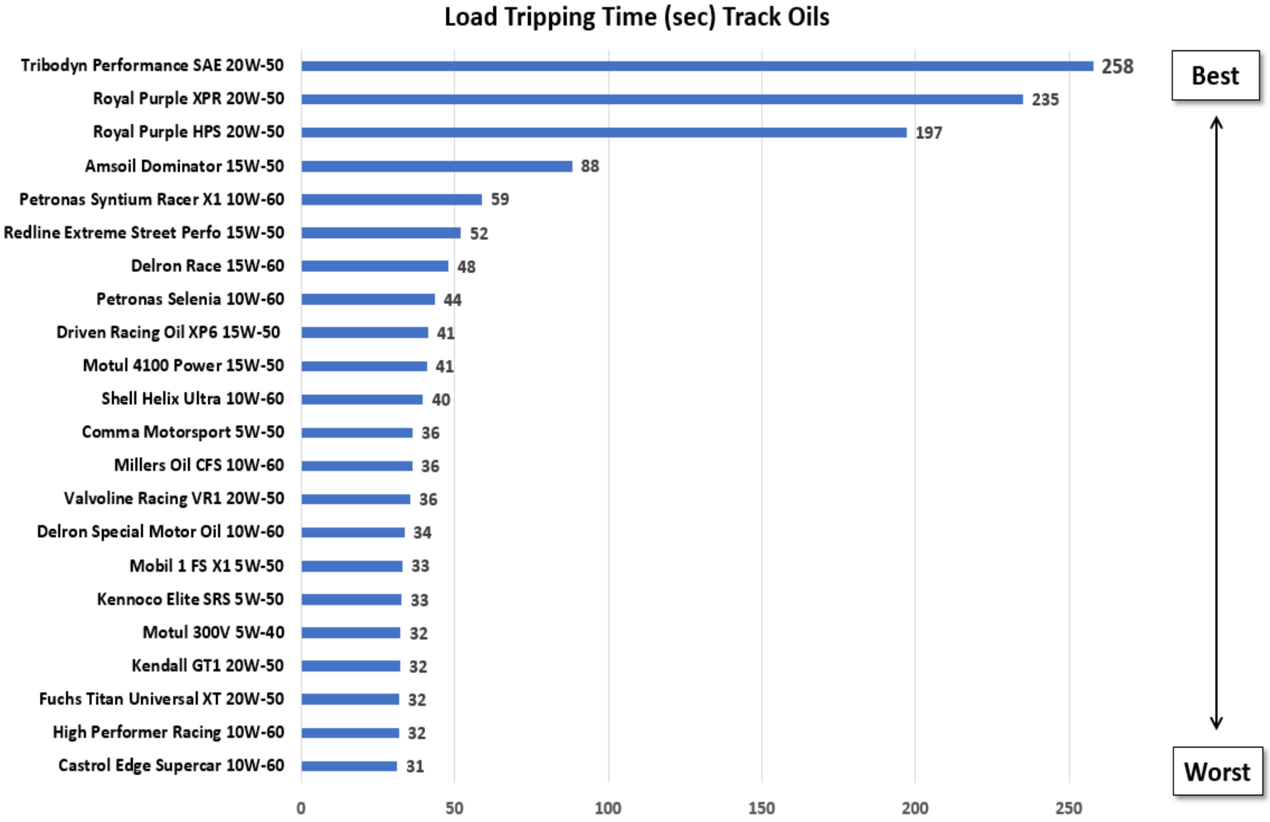


Chart 11: Price Quality Index (PQI) Street Oil Category

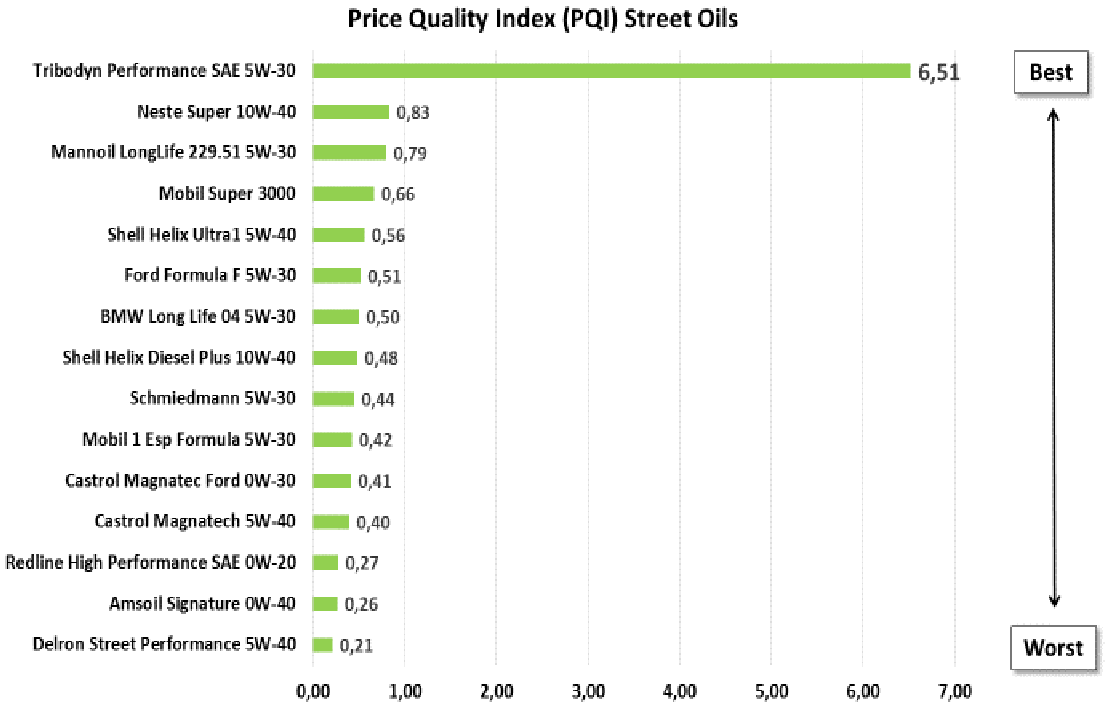
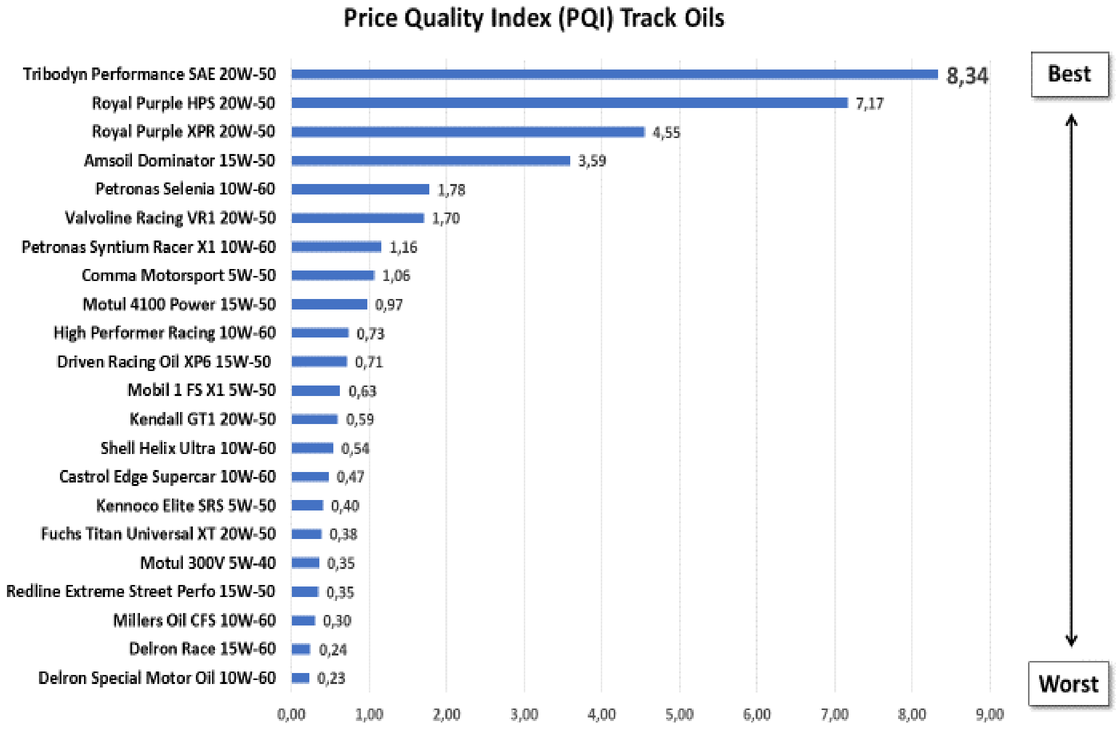


Chart 12: Price Quality Index (PQI) Track Oil Category



Dyno Test Results

Many manufacturers market their oils as low-friction lubricants enhancing engine torque and power. Such promoting is, however, done without explicit facts to back them up. As it makes perfect sense to assume that a high-performance oil with good tribological characteristics and film strength would actually affect engine torque and power positively, we decided to put the "rubber to the ground" and run the seven top film strength performers with similar viscosity ratings in a dynamometer from T A T Chassis Dyno Rolling Road Inertia Dyno Systems. The test car was a carefully tuned Toyota Celica ST 205.

Chart 7: Dyno test results

Kendall GT1 20W-50	310,3HP / 559,5 NM
Amsoil Dominator 15W-50	309,8 HP / 559,6 NM
Redline Extreme Street Performance 15W-50	309,3 HP / 558,4 NM
Castrol Edge Supercar 10W-60	309,4 HP / 559,0 NM
Delron Race 15W-60	311,2 HP / 560,7 NM
Royal Purple XPR 20W-50	310,2 HP / 557,3 NM
TriboDyn Performance Lubricants SAE 20W-50	312,3 HP / 559,3 NM

The dyno test results imply heat to be the biggest contributor for any losses. Some degree of lubricant impact on engine performance was detected, although the values are not comparable to the differences measured on actual oil film strengths. We have heard from several instances of oil lubricants contributing several percentage points on engine performance.

Conclusions

Film strength is the single most important characteristic of any oil lubricant in terms of protection against engine wear & tear caused by metal-to-metal friction, resulting in component failure and subsequent engine damage, accentuated under extreme temperature & pressure conditions. In the absence of official standardized methods to measure film strength, choosing a lubricant is typically based on subjective or hear-say opinions with very few scientific facts to support them.

The results of this unique and extensive research indicate remarkable film strength variations between oil lubricants. Based on the test results, long-life oil detergent and dispersant additives tend to decrease film strength, as they reduce the share of anti-wear (AW) and extreme pressure (EP) additives. Pressured by vehicle manufacturers' extended maintenance intervals, large global oil brands prioritize long-life additives with negative impact on film strength, compromising thus engine protection characteristics on their oil products.

Until this extensive and unique research, the absence of standardized methods to compare oil protection characteristics has resulted in end-user decisions affected by strong brand marketing, flashy advertising, and colorful stickers with superlative slogans on oil bottles. Tribologically advanced next generation lubricants can combine both good film strength with extended oil change intervals. The easily interpretable results of this study will greatly help car enthusiasts make right decisions to ensure proper engine protection and durability.