A Study of Motorcycle Oils

Second Edition

AMSOIL Power Sports Group

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Editor's Note: At the time of its original printing in December 2005, the *A Study of Motorcycle Oils* white paper represented the most comprehensive study of motorcycle oils ever published. The document served to educate hundreds of thousands of readers on the complex dynamic of motorcycle oil and motorcycle operation. The paper revealed, through an exhaustive series of relevant industry tests, that the motorcycle oils available to consumers varied greatly in quality and in their ability to perform the functions of motorcycle lubrication.

This second edition printing maintains the same scientific approach and includes the same testing protocol. Additional oils were tested, and some of the original oils tested differently than they had initially, indicating formulation changes. It should be noted that while some oils tested more poorly than they initially had, others showed improvement. Whether or not this improvement can be credited to the data revealed in the original publication remains a matter of speculation. In any case, as motorcycle oils continue to improve, consumers will benefit.

Overview

Motorcycles have long been used as a popular means of general transportation as well as for recreational use. There are nearly seven million registered motorcycles in the United States, with annual sales in excess of one million units. This trend is unlikely to change. As with any vehicle equipped with an internal combustion engine, proper lubrication is essential to insure performance and longevity. It is important to point out that not all internal combustion engines are similarly designed or exposed to the same types of operation. These variations in design and operation place different demands on engine oils. Specifically, the demands placed on motorcycle engine oils are more severe than those placed on automotive engine oils. Therefore, the performance requirements of motorcycle oils are more demanding as well.

Though the degree may be debatable, few will disagree that a difference exists between automotive and motorcycle applications. In which area these differences are and to what degree they alter lubrication requirements are not clear to most motorcycle operators. By comparing some basic equipment information, one can better understand the differences that exist.

The following comparison information offers a general synopsis of both automotive and motorcycle applications.

Vehicle	Equipment Type	Engine Cooling	Displacement	Lubricant Reservoir	Compression Ratio	Max. HP@ RPM	HP per C.I.
Honda Accord	Automotive	Water cooled	183 cu. in.	Single, engine only	10:1	240@6,250	1.3
Ford Explorer	Automotive SUV	Water cooled	281 cu. in.	Single, engine only	9.4:1	239@4,750	.85
Dodge Ram	L/D Truck	Water cooled	345 cu. in.	Single, engine only	9.6:1	345@5,400	.99
Chevrolet Corvette	Automotive Performance	Water cooled	366 cu. in.	Single, engine only	10.9:1	400@6,000	1.1
Honda CBR 1000 RR	Motorcycle Performance	Water cooled	61 cu. in.	Shared - engine & transmission	11.9:1	153@11,000	2.5
BMW R 1200 RT	Motorcycle Touring	Air & Oil cooled	71.4 cu. in.	Separate - engine & transmission	11.0:1	110@7,500	1.5
H/D Road King FLHRSI	Motorcycle Large Bore	Air cooled	88 cu. in.	Separate - engine & transmission	8.8:1	58@5,000	.66
Yamaha YZ450F	Motorcycle Motocross	Water cooled	27.1 cu. in.	Shared, engine & transmission	12.3:1	47.2@8,700	1.7

There are six primary differences between motorcycle and automotive engine applications:

1. **Operational Speed -** Motorcycles tend to operate at engine speeds significantly higher than automobiles. This places additional stress on engine components, increasing the need for wear protection. It also subjects lubricating oils to higher loading and shear forces. Elevated operating RPMs also promote foaming, which can reduce an oil's load-carrying ability and accelerate oxidation.

2. **Compression Ratios -** Motorcycles tend to operate with higher engine compression ratios than automobiles. Higher compression ratios place additional stress on engine components and increase engine operating temperatures. Higher demands are placed on the oil to reduce wear. Elevated operating temperatures also promote thermal degradation of the oil, reducing its life expectancy and increasing the formation of internal engine deposits.

3. **Horsepower/ Displacement Density -** Motorcycle engines produce nearly twice the horsepower per cubic inch of displacement of automobile engines. This exposes the lubricating oil to higher temperatures and stress.

4. **Variable Engine Cooling -** In general, automotive applications use a sophisticated water-cooling system to control engine operating temperature. Similar systems can be found in motorcycle applications, but other designs also exist. Many motorcycles are air-cooled or use a combination air/oil design. Though effective, they result in greater fluctuations in operating temperatures, particularly when motorcycles are operated in stop-and-go traffic. Elevated operating temperature promotes oxidation and causes oils to thin, reducing their load carrying ability.

5. **Multiple Lubrication Functionality -** In automotive applications, engine oils are required to lubricate only the engine. Other automotive assemblies, such as transmissions, have separate fluid reservoirs that contain a lubricant designed specifically for that component. The requirements of that fluid differ significantly from those of automotive engine oil. Many motorcycles have a common sump supplying oil to both the engine and transmission. In such cases, the oil is required to meet the needs of both the engine and the transmission gears. Many motorcycles also incorporate a frictional clutch within the transmission that uses the same oil.

6. **Inactivity -** Motorcycles are typically used less frequently than automobiles. Whereas automobiles are used on a daily basis, motorcycle use is usually periodic and in many cases seasonal. These extended periods of inactivity place additional stress on motorcycle oils. In these circumstances, rust and acid corrosion protection are of critical concern.

It is apparent that motorcycle applications place a different set of requirements on lubricating oils. Motorcycle oils, therefore, must be formulated to address this unique set of high stress conditions.

Purpose
The purpose of this paper is to provide information regarding motorcycle applications, their lubrication needs and typical lubricants available to the end user. It is intended to assist the end user in making an educated decision as to the lubricant most suitable for his or her motorcycle application.

Method
The testing used to evaluate the lubricants was done in accordance with American Society for Testing and Materials (ASTM) procedures. Testing was finalized in May 2009. Test methodology has been indicated for all data points, allowing for duplication and verification by any analytical laboratory capable of conducting the ASTM tests. A notarized affidavit certifying compliance with ASTM methodology and the accuracy of the test results is included in the appendix of this document. Five different laboratories were used in the generation of data listed within this document. In all cases blind samples were submitted to reduce the potential of bias.

Scope
This document reviews the physical properties and performance of a number of generally available motorcycle oils. Those areas of review are:

1. An oil's ability to meet the required viscosity grade of an application.
2. An oil's ability to maintain a constant viscosity when exposed to changes in temperature.
3. An oil's ability to retain its viscosity during use.
4. An oil's ability to resist shearing forces and maintain its viscosity at elevated temperatures.
5. An oil's zinc content.
6. An oil's ability to minimize general wear.
7. An oil's ability to minimize gear wear.
8. An oil's ability to minimize deterioration when exposed to elevated temperatures.
9. An oil's ability to resist volatilization when exposed to elevated temperatures.
10. An oil's ability to maintain engine cleanliness and control acid corrosion.
11. An oil's ability to resist foaming.
12. An oil's ability to control rust corrosion.

Individual results have been listed for each category. The results were then combined to provide an overall picture of the ability of each oil to address the many demands required of motorcycle oils.

Review Candidates

Two groups of candidate oils were tested, SAE 40 grade oils and SAE 50 grade oils. The oils tested are recommended specifically for motorcycle applications by their manufacturers.

SAE 40 Group

Brand	Viscosity Grade	Base	Batch Number
AMSOIL MCF	10W-40	Synthetic	11631 231
Bel-Ray EXS Super Bike	0W-40	Synthetic	AF 25940607
Castrol Power RS R4 4T	5W-40	Synthetic	14/02/28/C7011996
Honda HP4	10W-40	Syn / Petro Blend	7KJA0001
Lucas High Performance	10W-40	Syn / Petro Blend	None indicated on container
Maxima Maxum 4 Ultra	5W-40	Synthetic	1608
Mobil 1 Racing 4T	10W-40	Synthetic	X10C8 4967
Motul 300V Factory Line	10W-40	Synthetic	04611/03235M1
Pennzoil Motorcycle Oil	10W-40	Petroleum	HLPA418968/04237 21:00
Pure (Polaris) Victory	20W-40	Syn / Petro Blend	LT7 2 239
Royal Purple Max-Cycle	10W-40	Synthetic	ICPMO4701
Spectro, Platinum SX4	10W-40	Synthetic	16290
Suzuki, 4-Cycle Syn Racing	10W-40	Synthetic	HLPA358224/01106/03:47
Torco T-4SR	10W-40	Synthetic	PSPAG-L96296
Valvoline 4-Stroke	10W-40	Petroleum	0148C2

SAE 50 Group

Brand	Viscosity Grade	Base	Batch Number
AMSOIL MCV	20W-50	Synthetic	11678 253
Bel-Ray V-Twin	10W-50	Synthetic	AF22311106
BMW Super Synthetic	15W-50	Synthetic	17233
Castrol V-Twin	20W-50	Syn / Petro Blend	19/05/06 6003206
Harley Davidson HD 360	20W-50	Petroleum	0932C0798 1242
Harley Davidson SYN 3	20W-50	Synthetic	0021000248
Honda HP4	20W-50	Syn / Petro Blend	7IJA0001
Lucas High Performance	20W-50	Synthetic	None indicated on container
Maxima Maxum 4 Ultra	5W-50	Synthetic	28107
Mobil 1 V-Twin	20W-50	Synthetic	X04D8 4967
Motul 7100 Ester	20W-50	Synthetic	02610/A/83243
Pennzoil Motorcycle	20W-50	Petroleum	HLPA429090/07237 23:15
Royal Purple Max-Cycle	20W-50	Synthetic	ICPJ25705
Spectro, Platinum HD	20W-50	Synthetic	16785
Suzuki 4-Cycle V-Twin	20W-50	Syn / Petro Blend	HLPA351478/01096/10:34
Torco V-Series SS	20W-50	Synthetic	L90974 LRU1G SA
Valvoline 4-Stroke	20W-50	Petroleum	B268C2

Physical Properties, Performance Results and Prices

SAE Viscosity Grade (Initial Viscosity - SAE J300)

A lubricant is required to perform a variety of tasks. Foremost is the minimization of wear. An oil's first line of defense is its viscosity (thickness). Lubricating oils are by nature non-compressible and when placed between two moving components will keep the components from contacting each other. With no direct contact between surfaces, wear is eliminated. Though non-compressible, there is a point at which the oil film separating the two components is insufficient and contact occurs. The point at which this occurs is a function of an oil's viscosity. Generally speaking, the more viscous or thicker an oil, the greater the load it will carry. Common sense would suggest use of the most viscous (thickest) oil. However, high viscosity also presents disadvantages. Thicker oils are more difficult to circulate, especially when an engine is cold, and wear protection may be sacrificed, particularly at start-up. Thicker oils also require more energy to circulate, which negatively affects engine performance and fuel economy. Furthermore, the higher internal resistance of thicker oils tends to increase the operating temperature of the engine. There is no advantage to using an oil that has a greater viscosity than that recommended by the equipment manufacturer. An oil too light, however, may not possess sufficient load carrying ability to meet the requirements of the equipment.

From a consumer standpoint, fluid viscometrics can be confusing. To ease selection, the Society of Automotive Engineers (SAE) has developed a grading system based on an oil's viscosity at specific temperatures. Grading numbers have been assigned to ranges of viscosity. The equipment manufacturer determines the most appropriate viscosity for an application and indicates for the consumer which SAE grade is most suitable for a particular piece of equipment. Note that the SAE grading system allows for the review of an oil's viscosity at both low and high temperatures. As motorcycle applications rarely contend with low temperature operation, that area of viscosity is not relevant to this discussion.

The following chart identifies the viscosities of the oils before use. The purpose of testing initial viscosity is to ensure that the SAE grade indicated by the oil manufacturer is representative of the actual SAE grade of the oil, and that it is therefore appropriate for applications requiring such a fluid. The results were obtained using American Society for Testing and Materials (ASTM) test methodology D-445. The fluid test temperature was 100° C and results are reported in centistokes. Using SAE J300 standards, the SAE viscosity grades and grade ranges for each oil were determined and are listed below.

SAE 40 Group

Brand	Indicated Viscosity Grade	Measured Viscosity @ 100° C cSt	SAE Viscosity Range for 40 Grade	Within Grade
AMSOIL MCF	10W-40	14.45	12.5 to <16.3	Yes
Bel-Ray EXS Super Bike	0W-40	14.13		Yes
Castrol Power RS R4 4T	5W-40	12.95		Yes
Honda HP4	10W-40	13.75		Yes
Lucas High Performance	10W-40	13.56		Yes
Maxima Maxum 4 Ultra	5W-40	12.67		Yes
Mobil 1 Racing 4T	10W-40	13.98		Yes
Motul 300V Factory Line	10W-40	13.03		Yes
Pennzoil Motorcycle Oil	10W-40	15.24		Yes
Pure (Polaris) Victory	20W-40	14.60		Yes
Royal Purple Max-Cycle	10W-40	13.51		Yes
Spectro, Platinum SX4	10W-40	14.61		Yes
Suzuki, 4-Cycle Syn Racing	10W-40	14.72		Yes
Torco T-4SR	10W-40	15.60		Yes
Valvoline 4-Stroke	10W-40	15.22		Yes

SAE 50 Group

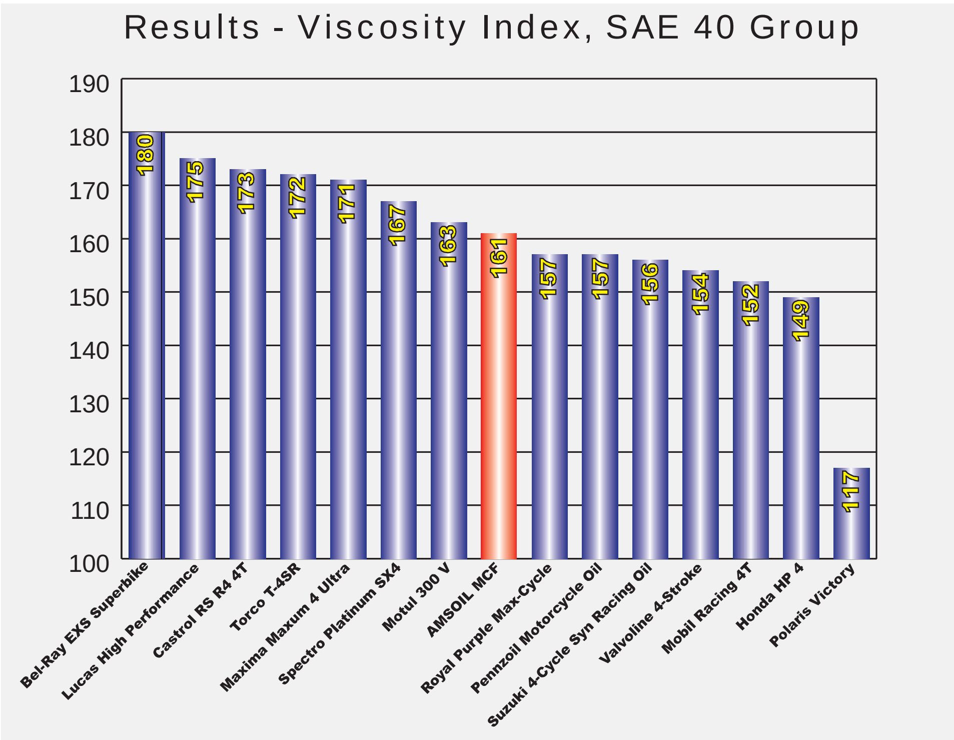
Brand	Indicated Viscosity Grade	Measured Viscosity @ 100° C cSt	SAE Viscosity Range for 50 Grade	Within Grade
AMSOIL MCV	20W-50	20.56	16.3 to < 21.9	Yes
Bel-Ray V-Twin	10W-50	16.95		Yes
BMW Super Synthetic	15W-50	17.88		Yes
Castrol V-Twin	20W-50	18.49		Yes
Harley Davidson HD 360	20W-50	20.50		Yes
Harley Davidson SYN 3	20W-50	20.38		Yes
Honda HP4	20W-50	17.58		Yes
Lucas High Performance	20W-50	17.75		Yes
Maxima Maxum 4 Ultra	5W-50	15.69		**No**
Mobil 1 V-Twin	20W-50	21.04		Yes
Motul 7100 Ester	20W-50	17.94		Yes
Pennzoil Motorcycle	20W-50	20.69		Yes
Royal Purple Max-Cycle	20W-50	20.09		Yes
Spectro, Platinum HD	20W-50	19.26		Yes
Suzuki 4-Cycle V-Twin	20W-50	19.82		Yes
Torco V-Series SS	20W-50	21.05		Yes
Valvoline 4-Stroke	20W-50	18.18		Yes

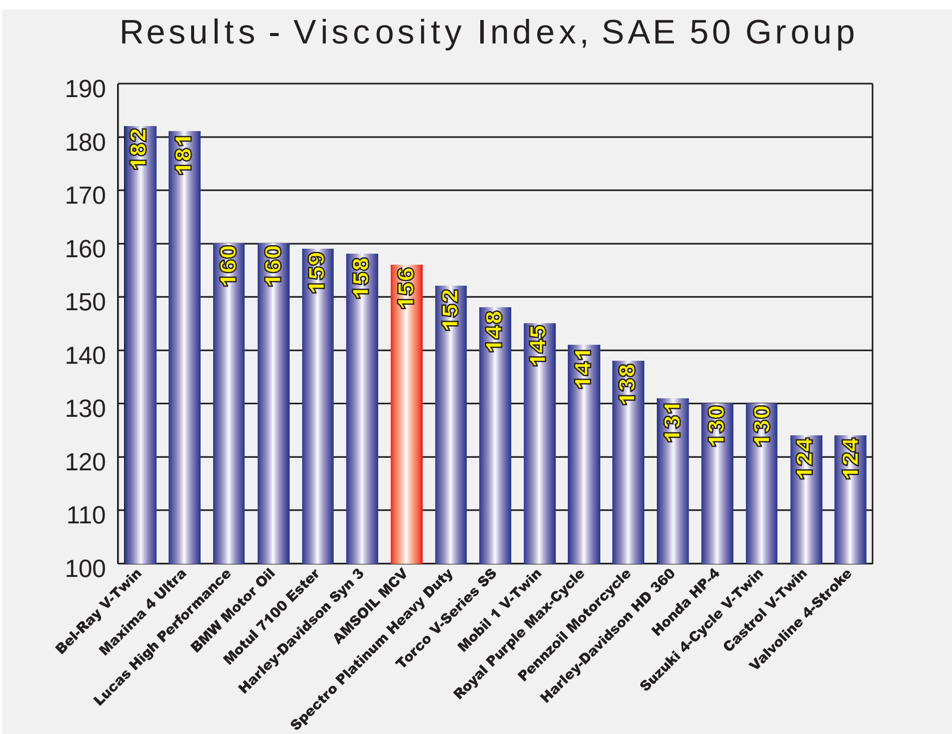
The results show that all of the oils tested except Maxima Maxum 4 Ultra 5W-50 have initial viscosities consistent with their indicated SAE viscosity grades. Those oils consistent with their indicated SAE viscosity grades are appropriate for use in applications recommending these grades/viscosities.

Viscosity Index (ASTM D-2270)

The viscosity (thickness) of an oil is affected by temperature changes during use. As the oil's temperature increases, its viscosity will decrease. The degree of change that occurs with temperature is determined by using ASTM test methodology D-2270. Referred to as the oil's Viscosity Index, the methodology compares the viscosity change that occurs between 100° C (212° F) and 40° C (104° F). The higher the viscosity index, the less the oil's viscosity changes with changes in temperature. While a greater viscosity index number is desirable, it does not represent that oil's high temperature viscosity or its load carrying ability. Shearing forces within the engine, and particularly the transmission, can significantly reduce an oil's viscosity. Therefore, oils with a lower viscosity index but higher shear stability can, in fact, have a higher viscosity at operating temperature than one with a higher viscosity index and lower shear stability.

Ambient temperatures can also effect an oil's viscosity. Oil thickens as outside temperatures decrease, leading to pumpability and circulation concerns. Oils with high viscosity indices function better over a broader temperature range than those with lower numbers. This is important if equipment is used year round in colder climates.

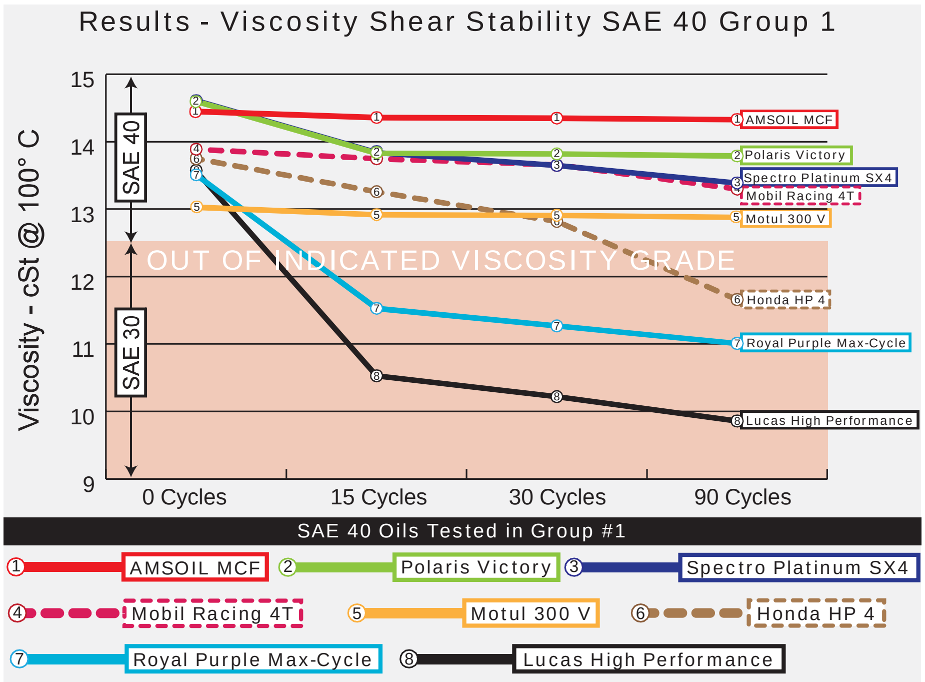


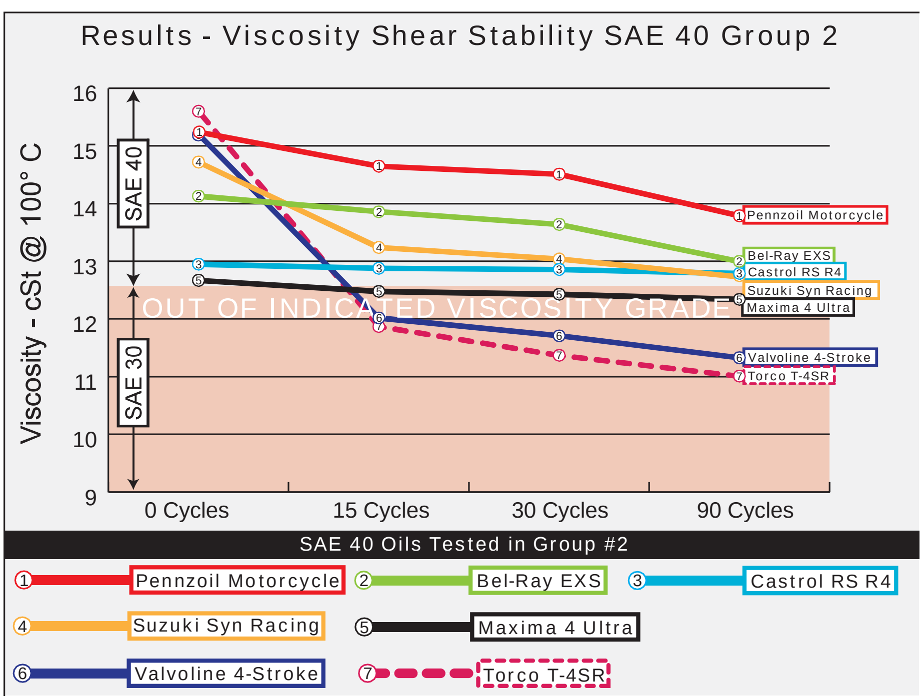


Viscosity Shear Stability (ASTM D-6278)

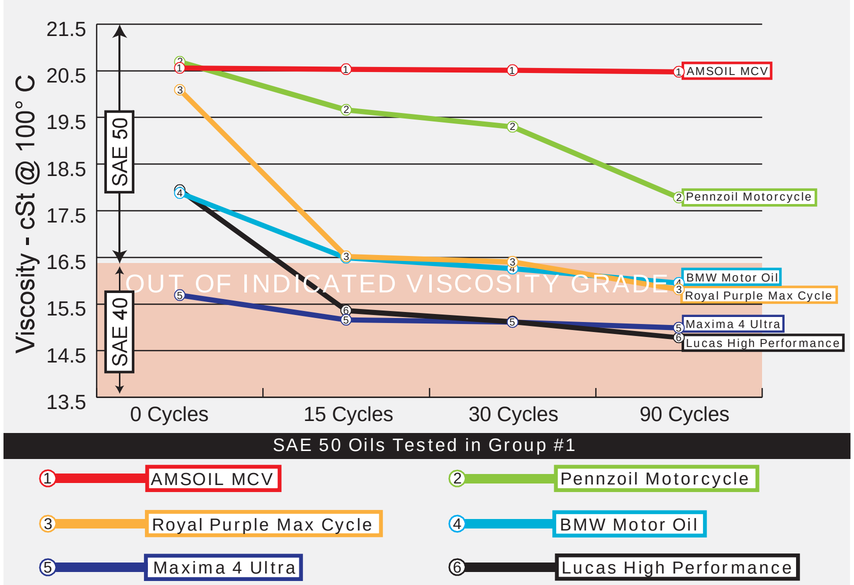
An oil's viscosity can be affected through normal use. Mechanical activity creates shearing forces that can cause an oil to thin out, reducing its load carrying ability. Engines operating at high RPMs and those that share a common oil sump with the transmission are particularly subject to high shear rates. Gear sets found in the transmissions are the leading cause of shear-induced viscosity loss in motorcycle applications.

The ASTM D-6278 test methodology is used to determine oil shear stability. First an oil's initial viscosity is determined. The oil is then subjected to shearing forces using a test apparatus outlined in the methodology. Viscosity measurements are taken at the end of 15, 30 and 90 cycles and compared to the oil's initial viscosity. The oils that perform well are those that show little or no viscosity change. Oils demonstrating a significant loss in viscosity would be subject to concern. The flatter the line on the charts below, the greater the shear stability of the oil. Each SAE grade was split into two or more groups to make the charts easier to reference.

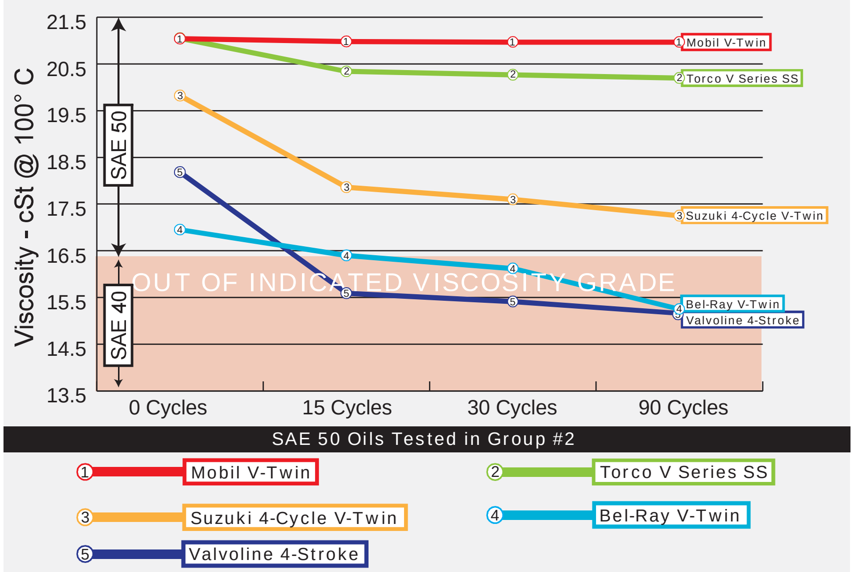




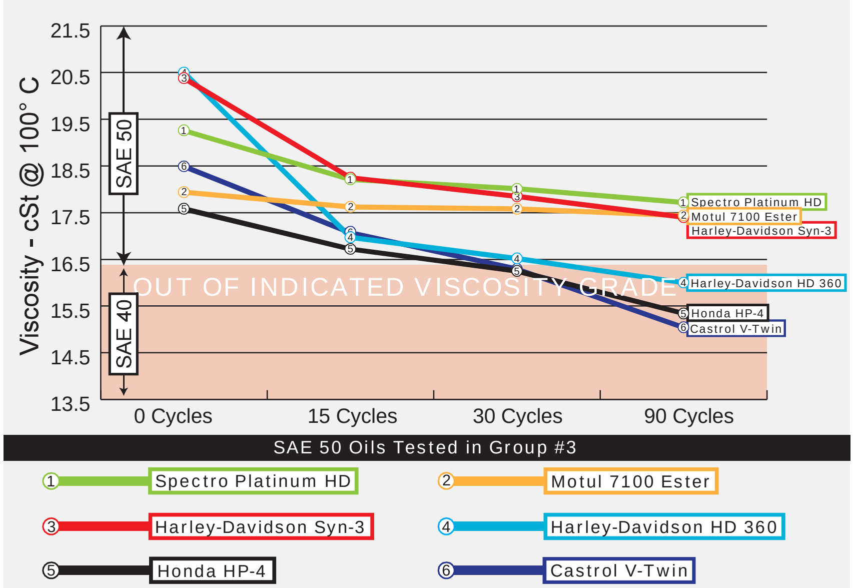
Results - Viscosity Shear Stability SAE 50 Group 1



Results - Viscosity Shear Stability SAE 50 Group 2



Results - Viscosity Shear Stability SAE 50 Group 3



The results point out significant differences between oils and their ability to retain their viscosity. Within the SAE 40 group, 40% of the oils dropped one viscosity grade to an SAE 30. Within the SAE 50 group, 53% dropped one grade to an SAE 40. Many of the oils losing a viscosity grade did so quickly, within the initial 15 cycles of shearing.

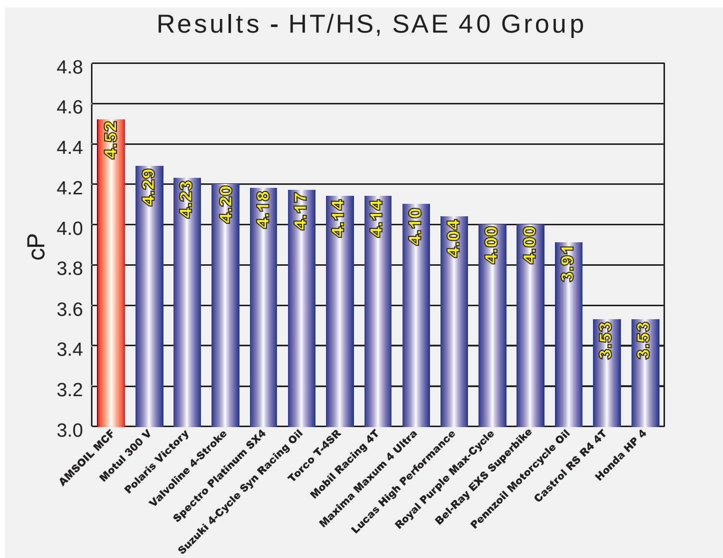
In order to meet motorcycle oil standards JASO T903:2006 and ISO 24254:2007, SAE 40 oils must not shear below 12 cSt in 30 cycles and SAE 50 oils must not shear below 15 cSt in 30 cycles. In the test, no SAE 50 oils fell below 15 cSt at 30 cycles. Maxima 4 Ultra and Lucas High Performance, however, fell below the 15 cSt limit prior to 90 cycles. In the SAE 40 group, Royal Purple Max-Cycle, Lucas High Performance, Torco T-4SR and Valvoline 4-Stroke fell below the 12 cSt limit in 30 cycles, while Honda HP4 fell below the limit in 90 cycles.

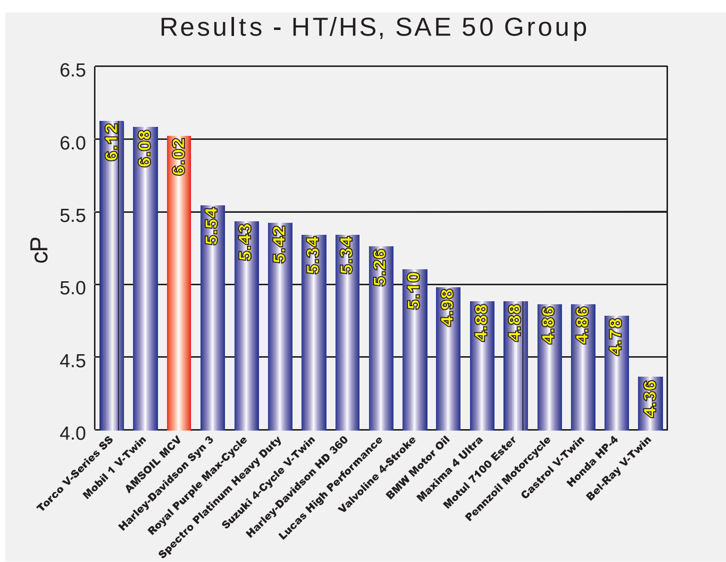
The importance of shear stability cannot be overstated. This same test is used to evaluate heavy duty diesel engine oils subjected to service intervals as high as 50,000 miles in Class 8 trucks.

It should be noted that no correlation exists between the viscosity index of an oil and its ability to minimize shear. In the SAE 40 group, for example, the Lucas High Performance had the second-highest viscosity index, yet performed the worst when it came to viscosity retention in the face of shearing forces. The AMSOIL MCF, on the other hand, had a significantly lower viscosity index, yet placed first in the area of viscosity retention.

High Temperature/High Shear Viscosity (HT/HS ASTM D-5481)

Shear stability and good high temperature viscosity are critical in motorcycle applications. How these two areas in combination affect the oil is measured using ASTM test methodology D-5481. The test measures an oil's viscosity at high temperature under shearing forces. Shear stable oils that are able to maintain high viscosity at high temperatures perform well in the High Temperature/High Shear Test. The test is revealing as it combines viscosity, shear stability and viscosity index. It is important because bearings require the greatest level of protection during high temperature operation. Test results are indicated in cetipoises (cP), which are units of viscosity. The higher the test result, the greater the level of viscosity protection offered by the oil.



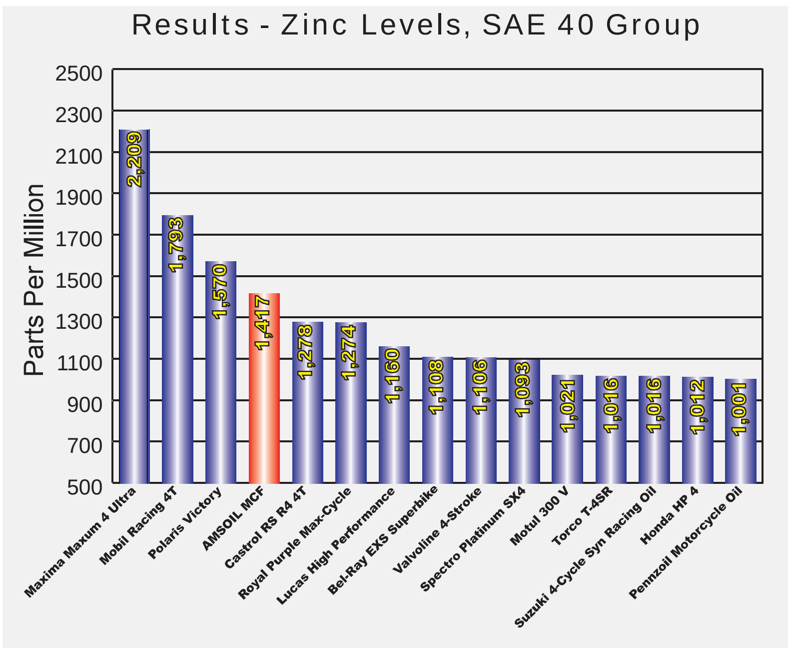


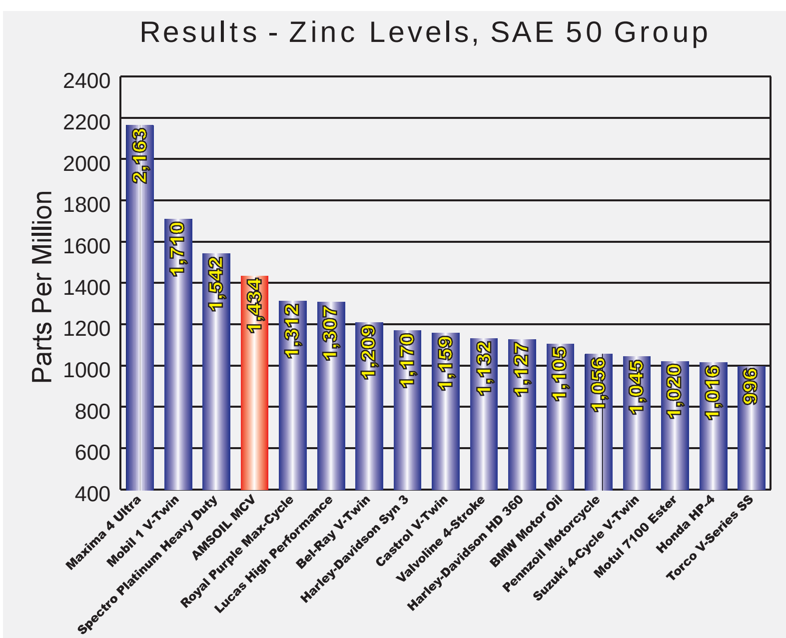
Zinc Concentration (ppm, ICP)

Though viscosity is critical in terms of wear protection, it does have limitations. Component loading can exceed the load carrying ability of the oil. When that occurs, partial or full contact results between components and wear will occur. Chemical additives are added to the oil as the last line of defense to control wear in these conditions. These additives have an attraction to metal surfaces and create a sacrificial coating on engine parts. If contact occurs the additive coating takes the abuse to minimize component wear. The most common additive used in internal combustion engine oils is zinc dithiophosphate (ZDP). A simple way of reviewing ZDP levels within an oil is to measure the zinc content. It should be noted that ZDP defines a group of zinc-containing compounds that vary in composition, quality and performance. Quantity of zinc content alone does not indicate its performance. Therefore, it cannot be assumed that oils with higher concentrations of zinc provide better wear protection. Additional testing must be reviewed to determine an oil's actual ability to prevent wear. The wear testing further in this document reflects the general lack of correlation between zinc levels and wear protection. Due to this lack of correlation, zinc levels are not included in the scoring and summary of results contained in the review.

The tables below show the levels of zinc present in each of the oils. Results were determined using an inductively coupled plasma (ICP) machine and are reported in parts per million.

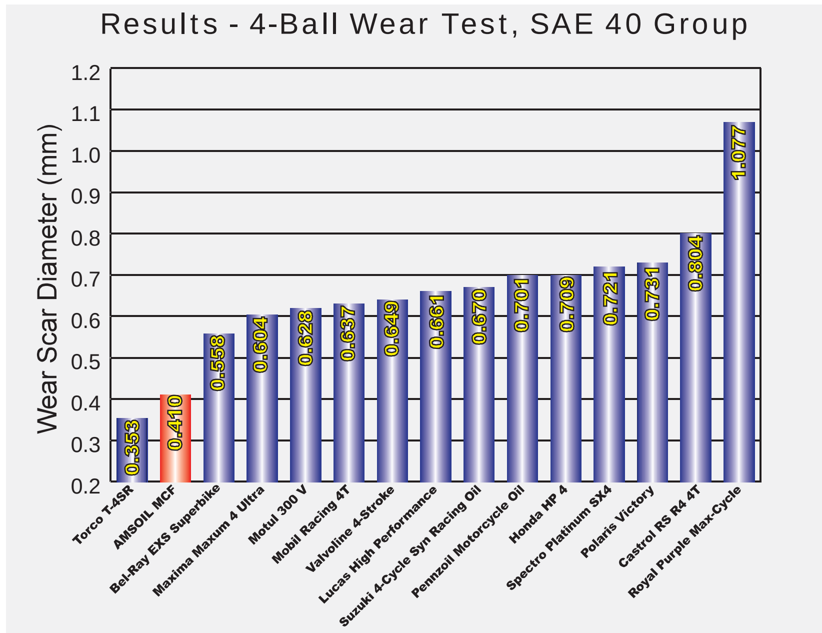
Zinc levels varied widely in both the SAE 40 and 50 groups, ranging from as low as 996 ppm to as high as 2,209 ppm.

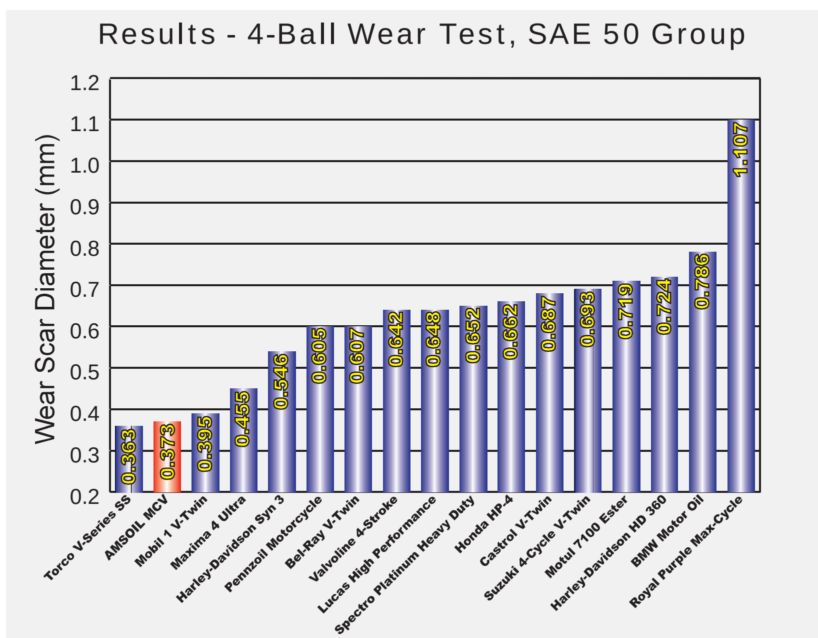




Wear Protection (4-Ball, ASTM D-4172)

The ASTM D-4172 4-Ball Wear Test is a good measure of an oil's ability to minimize wear in case of metal-to-metal contact. The test consists of a steel ball that sits atop three identical balls that have been placed in a triangular pattern and restrained from moving. All four balls are immersed in the test oil, which is heated and maintained at a constant temperature. The upper ball is then rotated and forced onto the lower three balls with a load measured in kilogram-force (kgf). After a one-hour period of constant load, speed and temperature, the lower three balls are inspected at the point of contact. Any wear will appear as a single scar on each of the lower balls. The diameter of the scar is measured on each of the lower balls and the results are reported as the average of the three scars, expressed in millimeters. The lower the average scar diameter, the better the anti-wear properties of the oil. In this case, the load, speed and temperature used for the test were 40 kg, 1800 RPMs and 150° C respectively.





Torco and AMSOIL motorcycle oils finished first and second respectively in both the SAE 40 and SAE 50 groups. Interestingly, Torco oils had among the lowest zinc levels of all oils tested, while the AMSOIL oils had zinc levels in the middle to upper range. Although the Maxima oils contained the highest levels of zinc, each placed fourth in its respective 4-Ball Wear Test. Royal Purple oils featured zinc levels similar to those of the AMSOIL oils. However, the wear scars were 2.6 to 2.8 times greater and they ranked last in each test.

The results strongly suggest that simply having high levels of zinc is not sufficient to effectively minimize wear.

Gear Performance (FZG ASTM D-5182)

Wear protection is provided by both the oil's viscosity and its chemical additives. The greatest need for both is in the motorcycle transmission gear set. High sliding pressures, shock loading and the shearing forces applied by the gears demand a great deal from a lubricant. Motorcycle applications present a unique situation because many motorcycle engines share a common lubrication sump with the transmission. The same oil lubricates both assemblies, yet engines place different demands on the oil than do transmissions. What may work well for one may not work well for the other. In an attempt to meet both needs, a lubricant's performance can be compromised in both areas.

To examine gear oil performance, the ASTM test methodology D-5182 (FZG) is used. In this test, two hardened steel spur gears are partially immersed in the oil to be tested. The oil is maintained at a constant 90° C and a predetermined load is placed on the pinion gear. The gears are then rotated at 1,450 RPM for 21,700 revolutions. Finally, the gears are inspected for scuffing (adhesive wear). If the total width of wear on the pinion gear teeth exceeds 20 mm, the test is ended. If less than 20 mm of wear is noted, additional load is placed on the pinion gear and the test is run for another 21,700 revolutions. Each time additional load is added, the test oil advances to a higher stage. The highest stage is 13. Results indicate the stage passed by each oil. Wear is reported for the stage at which the oil failed.

Pass Example:
AMSOIL MCF
Passed Stage 13,
Total Wear 0 mm

Failure Example:
Torco T-4SR
Passed Stage 12,
Failed Stage 13,
Total Wear in
Stage 13, 320 mm