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Four-Ball Friction and Wear Test

A Four-Ball Friction and Wear test is used to measure the friction and wear characteristics of a fluid or semi-fluid material.

The figure below shows the heart of the tester. Three ½-in steel balls are rigidly clamped into a cup and covered with the test fluid. A fourth ball, in a chuck on top of the three bottom balls, makes point contact with each of the other three.

During the test, a load (usually 40kg, 392N) is applied between the top and bottom balls and the top ball is rotated at 600 or1200 rpm. Using a load cell, we can measure the frictional force, from which we get the coefficient of friction values.

At the end of the test period, the cup with the three balls is removed from the four-ball test machine and the test fluid is poured out. Each of the bottom, stationary balls now has a small round wear scar where the top, rotating ball made sliding contact under the 40 kg (392N) load. These contact spots are the wear scars that we measure using a microscope.

From the torsion that we measure with the load cell and the test load applied, we can derive the coefficient of friction; and from the average diameter of the wear scars, we have a measure of wear for a given fluid. Both of these values are quite repeatable.

Just to give some sense of proportion, the wear scars of a fresh, high-quality motor oil would have a diameter of 0.60 to 0.66 mm under standard ASTM D 2266 test conditions (1200RPM, 40kg load, 75 C for one hour). Some exotic racing oils might go as low as 0.35 mm. The coefficient of friction for these oils would be 0.090 to 0.125 for the high-quality motor oil, and for the exotic racing oils it can be as low as 0.040.

The difference between 0.35 mm and 0.60 mm wear scar diameter may not seem that big, but it's actually the volume of metal removed that is important. A 0.60 mm diameter wear scar has a volume that is 10 times larger than the volume of a 0.35 mm diameter wear scar.

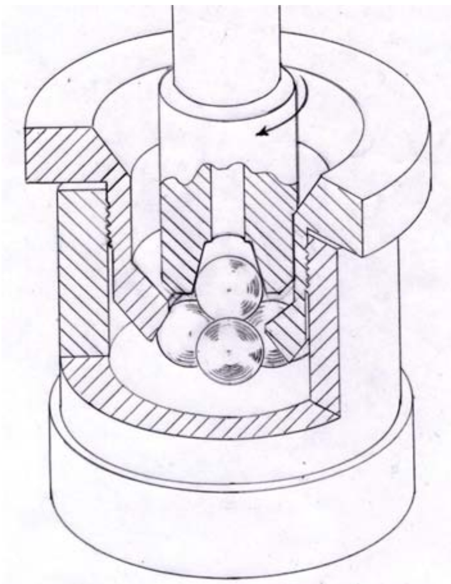
Types of Lubrication Conditions

There are several lubrication conditions that have been described and named; the two main conditions are hydrodynamic and boundary. Hydrodynamic lubrication is the type in which the sliding bearing surfaces are separated by a fluid film. Under hydrodynamic lubrication conditions there will be no wear, although (under certain conditions) there could be erosive or corrosive wear.

Boundary lubrication conditions exist where we have solid-to-solid sliding contact. The solid does not have to be the bearing material; it is often a solid film formed on the bearing material. Since the 1960s, all motor oils have an additive, ZDDP, that forms a thin solid film on the bearing surfaces. When that film wears through, the friction increases, things get hotter, and some more film forms. This film is called a boundary lubrication film. Because of this mechanism, we don't need to rebuild car engines every 40,000 miles anymore.

Any time we see wear, we have boundary lubrication conditions. The amount of wear can be very small, and the worn surface film can even repair itself like the boundary film formed by the ZDDP. The point is, under these test conditions, a solid (or something very close to a solid) is being worn away, and therefore is in sliding contact with another solid; this is boundary lubrication.

Because of its high unit loading (roughly 300,000 psi at the start), the four-ball tester operates almost exclusively in the boundary regime.



Therefore, we need to remember when testing a fluid with the four-ball tester that we are evaluating its friction and wear characteristics in the boundary regime. If the fluid is never exposed to those boundary conditions but is always in the *hydrodynamic* regime, the four-ball data will have no relevance. If even a very small amount of wear is taking place in the normal application of the fluid, then the four-ball test will have some relevance.

Four-Ball Test Methods

There are several ASTM four-ball test methods. All of them measure wear, but only one measures friction as well. The ASTM test method that does measure friction does it only for ten minutes, then increases the load again for another ten minutes, and so on. This method enables us to see the friction coefficient only during the run-in period. But what is often of greater interest is the coefficient of friction after some equilibrium has been reached. If it's not possible to reach equilibrium, that would also be good to know — but we cannot know that after a test of only ten minutes.

But there is much more information to be gleaned from every four-ball test, and that information is readily available.

The friction trace tells us what is going on at the contact surface. A smooth trace tells us that a strong boundary film has formed and that very little wear of the underlying surface is taking place. If the friction trace shows a lot of spikes, however, we know the boundary film is not very strong and that it's breaking with each spike and allowing additional wear of the underlying surface.

Other pieces of useful information too often discarded from four-ball tests are the condition of the wear scar itself and the nature of the deposits that form around the wear scar. These deposits are usually the oxidized test fluid. The deposits can form at the entrance and/or the exit of the wear scar, often above and below the wear scar as well, and sometimes within the wear scar itself. If the oxidation stability of the test fluid is very good, there will be no deposits. If we do find deposits in or around the wear scar, that is a very good predictor of what we can expect in actual use.

Sometimes we find the exit side of the wear scar has been etched. This tells us that with the additional heating, from going through the wear scar, caused some decomposition (possibly of a chlorine compound), which in turn reacted with some moisture to form HCl and etching the metal surface.

Benefits of Four-Ball Tests

From one four-ball test we can do all of the following:

- Determine the friction and wear.
- Get a good indication of oxidation stability.
- Get a good idea of the film strength.
- Get a good indication of the likelihood of sticky deposit.
- And even get an indication if there are unstable and reactive components in the test fluid.

We can do this with greases, synthetic oils, mineral oils, water-based solutions or emulsions — or just about any other fluid we can come up with. We can also evaluate the bearing material itself by using those materials as the test samples, and all of this can be done with a very high degree of repeatability. 12/03