

Nanodiamonds (NDs), with 5nm primary particles sizes, are among the most promising nanoparticle lubricant additives since they are superhard and capable of dramatically reducing wear and friction of sliding surfaces. NDs in lubricants can provide the following global benefits for a wide range of industrial and transportation systems:



(i) reduced fuel consumption, (ii) reduced oil consumption through increased lubricant longevity, and (iii) increased longevity of components experiencing friction. D-Tribo™ produced by Adámas Nanotechnologies, Inc. is a nanodiamond-based, engineered oil additive and has demonstrated very impressive performance in tests involving gasoline engines, diesel engines, and in laboratory tests, which are summarized below.

OEM approved bench and field fuel efficiency (FE) tests on gasoline engines

An independent test laboratory in the US was commissioned to evaluate the performance of the additive with respect to improving the fuel economy in 4-cycle gasoline powered automobile engines. A baseline fuel usage in three diverse engines was established. A proprietary testing protocol was used that included “city cycle” and high speed cruise. Each engine, prior to the baseline test, had a fresh oil change using Mobil 5W-30 SN motor oil. The engines were a 6.5HP Briggs+Stratton 4-cycle, a Mercury Mariner SUV 3.0L, and a Toyota Corolla 1.6L. After the baseline fuel mileage was determined, D-Tribo™ was added. The engines were run for 8 to 12 hour periods prior to fuel economy testing in order to fully activate the additive (this time period was decided based upon preliminary testing on a High Frequency Rotating Rig, HFRR).

1) The Briggs+Stratton engine showed a 0.5 to 1.5% improvement in fuel economy.

2) The Mercury engine test was conducted by a Lincoln/Mercury dealership under the supervision of the independent test laboratory. A driving test cycle was designed using the Ford computerized fuel economy test system. The computer was installed in a 2008 Mercury SUV 3.0 L engine, and then the vehicle was engaged in a test cycle consisting of a prescribed stop and go, acceleration, steady RPM running, etc.

The baseline gas mileage was 23.7 mpg. After addition of D-Tribo™, the vehicle was run for two weeks. The vehicle averaged 24.5 mpg after addition of D-Tribo™. The test was extended and the mpg continued to range from 24.3 to 24.7 mpg. This demonstrates an improvement of about 3.5%. The test was repeated as the improvement exceeded expectations. Again, results ranged from a 3.1 to 3.9% gain. Other fuel economy improving additives tested by the independent test laboratory previously resulted in either no improvement or less than 1%. As a comparison the laboratory recorded a 1 to 2% increase in fuel economy using the Mobil 1 Fuel Economy oil formulation.

3) The third test involved a Toyota Corolla. For this vehicle, a “long term” test (6 weeks) to verify fuel mileage over an extended period of time was performed. For the first two weeks of testing, mileage ranged from 28.3 to 28.7 mpg. The mpg then suddenly increased to a range of 29.7 to 30.1 mpg and remained stable - a 4.5% improvement in fuel efficiency.

Summary by the independent test laboratory from the gasoline engine tests: “Through multiple tests on various engines using state of the art technology and a comprehensive test protocol, there is a definitive and significant fuel economy improvement when using D-Tribo™ top additive. That improvement will vary due to different engine designs and driving styles.”



Personal tests on passenger cars

In the tests, a 2003 Toyota Celica and a 2002 Ford Focus were used. Before the oil was changed, the cars had an average gasoline consumption of 29.5 mpg and 31.4 mpg, respectively. After an oil change (5W30 Exxon Mobile Superflow oil for the Toyota and 10W30 Pennsoil for the Ford), D-Tribo™ was added to 4 quarts of the motor oil for each car. Following successive gas fillings, the gas mileage calculated for the Toyota was: 30.6, 30.0, 32.8, 31.2, and 31.2 mpg. For the Ford, the calculated gas mileage was: 30.7, 33.2, and 33.5 mpg. On average, improvement in fuel consumption efficiency was 5.6% (31.2mpg) for the Toyota and 3.4% (32.5mpg) for Ford. In both tests, after the first 1-2 gas fillings, the observed improvement was modest (Toyota) or no improvement was observed (Ford). However, after that, gasoline consumption improvement stabilized at a level of approximately 5%. In both cars, the engines worked more quietly after introducing the additive.

OEM approved bench and field fuel efficiency (FE) tests on diesel engines

An independent test laboratory in the US was commissioned to evaluate the effectiveness of D-Tribo™ in diesel engines. Tests were done using Delo 400 LE SAE 15W40 diesel engine oil. Three engines comprising over 70% of the types of diesel engines on the road were used: Cummins, Ford Super Duty, and a GM Detroit Diesel. The GM Duramax has a 14 quart capacity, the Cat "13" has a 12 Gallon fill including the aux cooler, and the Ford 350 SD "T" takes 15 quarts. A baseline with Delo 400 was established with protocols in a city/highway cycle. The tests were done on Dyno and/or SG-2 and field tests. Engine performance (HP/TQ (horsepower/torque) and emissions) were recorded for all engines throughout the test cycles.

Ford SD 7.4 LT (Cummins) Diesel: This turbo charged engine is a modern V-8 longer stroke "high" power design (440 HP) (860 TQ). The baseline FE ranged from 13.5 mpg to 18.5 mpg for city and highway cycles, correspondingly. After addition of D-Tribo™, the FE improvement was observed after 2 hours of testing and stabilized after a 5 hour period. The FE improvement ranged from 1% for the highway cycle to a maximum of 4% during a high temperature, high load engine test sequence. The averaged FE improvement was 1.5% to 2%. This is considered a significant improvement in FE for diesels. HP/TQ showed a 1% improvement and stabilized. Emissions stayed within the range of error. Importantly, no engine performance problems were observed. This was not the case for other friction modifiers for diesel engines tested by the same Laboratory. "Long term" testing demonstrated that the additive functions effectively over the full oil change cycle.

6.5 LT Duramax Diesel: This GM diesel engine is a modern short stroke high compression design. The baseline FE ranged from 13 mpg to 20 mpg, for the city and highway cycles, respectively. After addition of D-Tribo™, the FE improvement stabilized after a period of 3 hours.

The FE improvement ranged from 1% for the highway cruise mode to a maximum of 3% during a high temperature, high load engine test sequence. The averaged FE improvement was 1.3%. Horsepower and torque increased slightly, and oil temperature was slightly lower. No detriment to emissions was noted.

Caterpillar 13: The Cat 13 is a large block turbo diesel engine used primarily in big rig 16 and 18 wheelers. The FE baseline range was 6 to 10 mpg, depending upon load and type of driving. Overall, the FE improvement for this engine was about 1%. HP/TQ increased slightly and oil temperature was slightly lower. No detriment to emissions was noted.



Laboratory tests

Several hundred tests have been run at the International Technology Center (ITC) (Raleigh, NC, USA) using a Bruker's UMT-3 high-load tribometer for optimization of the D-Tribo™ composition. The coefficient of friction measured as a function of time (Fig. 1) using a block-on-ring module (Fig. 2) for pure Mobil Super 5W30 SN oil and Mobil containing D-Tribo™ are shown. Hardness of blocks and rings were H30 and H60, respectively. The size of the wear scar of the block tested with the additive in oil was twice less than that for pure oil (Fig. 2). Characterization of the friction surfaces after the tribotests using electron microscopy and Zygo 3D optical profiler demonstrated significant polishing of the surfaces in the tests performed with oil containing D-Tribo™ (Fig.3). The mechanism of action is shown in Fig.4.

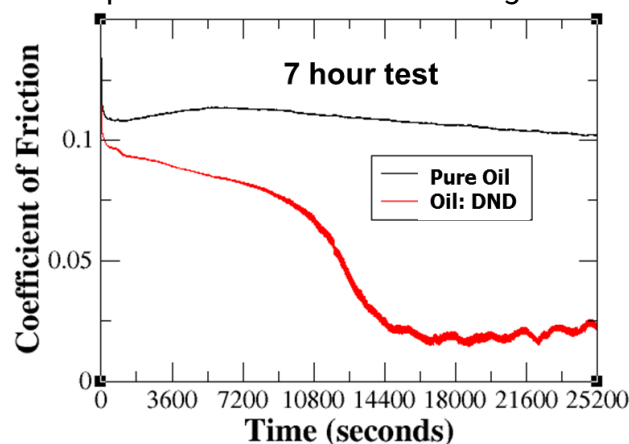


Figure 1. Coefficient of friction measured as a function of time in the block-on-ring test for pure Mobil Super 5W30 SN oil and the oil containing D-Tribo™. Rotation speed was 200rpm and the load was 30kg.

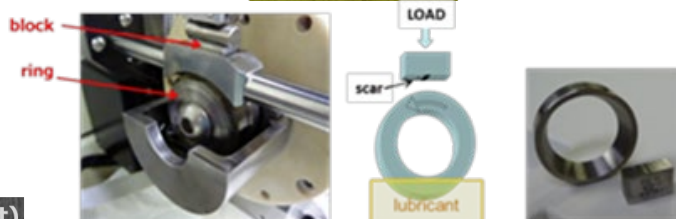
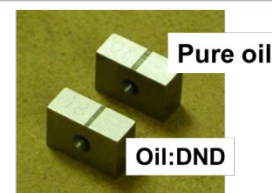
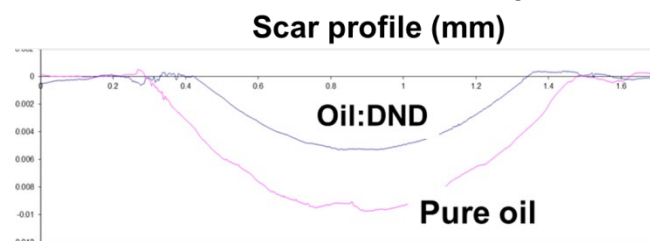


Figure 2. (Top) Scar profiles measured in the block-on-ring 7 hour test for pure Mobil Super 5W30 SN oil and the oil containing D-Tribo™. Rotation speed was 200rpm and the load 30kg. Hardness of blocks and rings were H30 and H60, correspondingly. Followed by Block-on-ring test module setup

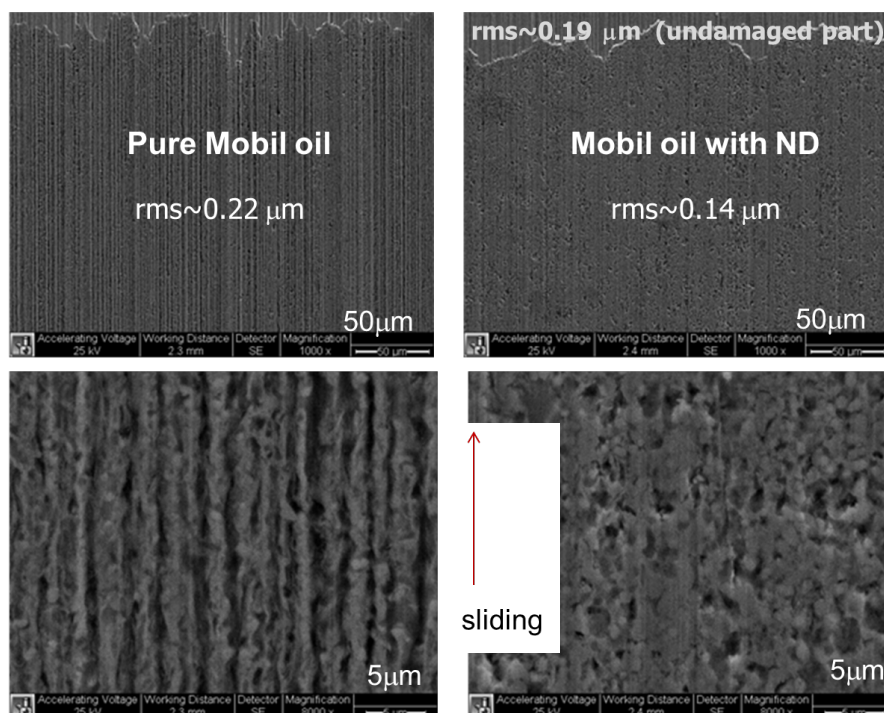
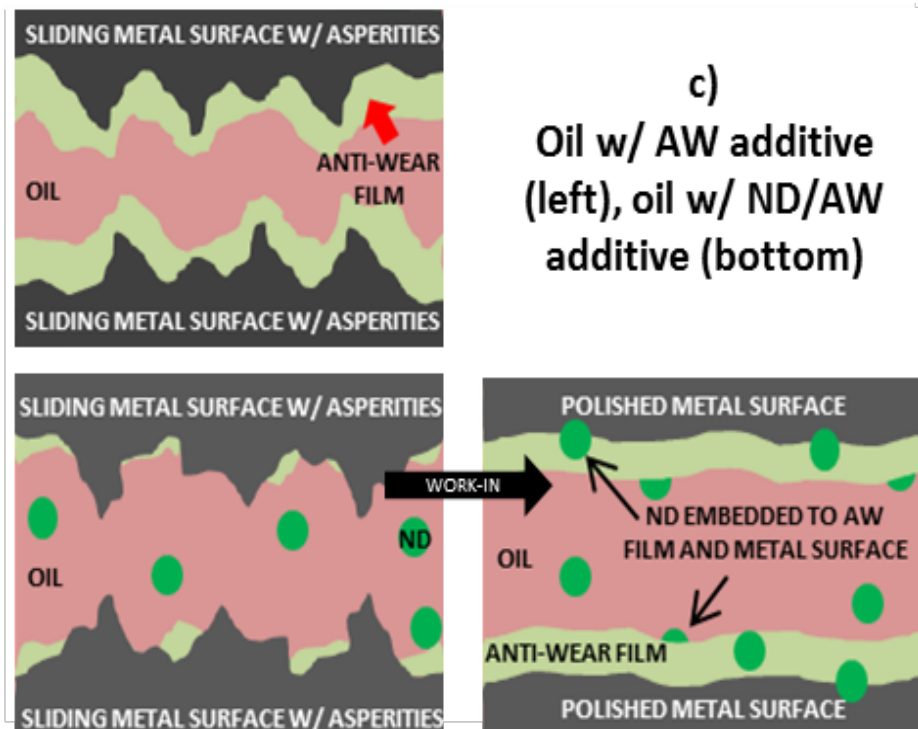


Figure 3. Scanning electron microscopy images of the surfaces within scars in blocks formed during the 7 hour test for pure Mobil Super 5W30 SN oil and the oil containing D-Tribo™. Rotation speed was 200rpm and the load was 30kg. Hardness of blocks and rings were H30 and H60, respectively.



Figure 4. Possible mechanism of action of combination of nanodiamonds (NDs) and a typical antiwear additive (AW). NDs contribute to the efficient polishing of the asperities during the initial stage of sliding of the friction surfaces against each other, while the AW agents form a protective film.



- After some time (a “work-in” period), a well-polished surface protected by a tribo film is formed possibly reinforced with incorporated ND particles. Reinforcement with NDs can be extended, in principle, to the incorporation of NDs into the metallic substrate, depending on the hardness of the substrate. It is presumed that the onset of the drop in the friction coefficient (Fig. 1) coincides with the point at which the surface is well polished. When the average roughness of the surface is highly uniform after polishing, not only does this remove high stress concentrators which increase wear, but it may also allow for a more uniform protective anti-wear film to be established. The amount of the AW additive needed for

the protection is a few times (up to 5 times) less than typically recommended, when used in combination with NDs.

DTribo™ options for distributors:

Brand	Composition	Recommended dilution with fully formulated oil*
DTribo	ND particles, proprietary dispersant, base oil (PAO-6), AW synergistic additive	1:60 to 1:100
DTribo-2	Same as Dtribo, but at higher concentration**	1:120 to 1:200

*fully formulated oils: motor oils (for gasoline and diesel engines), gear oils.

**DTribo-2 provides benefits of reduced shipping cost while same amount of the fully formulated oil (FF oil) can be treated. It would require more thorough mixing with FF oil.

