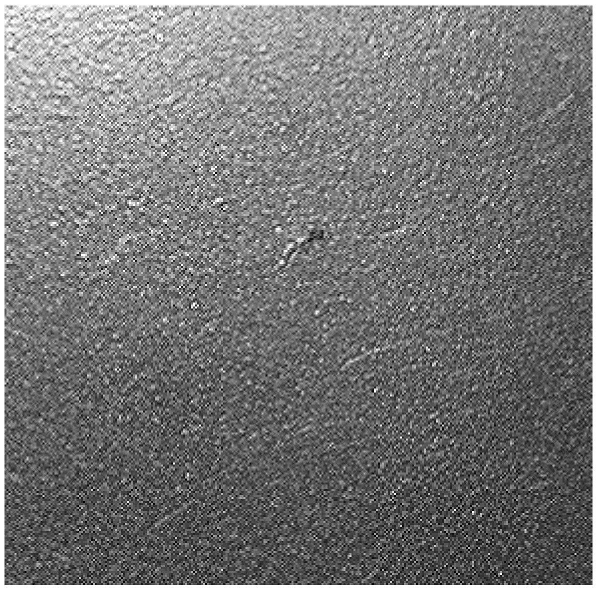
TRIBOLOGICAL PROPERTIES OF PTFE COOKWARE COATINGS



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INTRO

Polytetrafluoroethylene (PTFE, more commonly known as Teflon) polymer has one of the lowest coefficient of friction, COF, and, depending on the loads applied, good wear resistance. Due to the aggregate effect of carbon-fluorine bonds, PTFE exhibits superior chemical inertness, high melting point of 327 °C (620 °F), and maintains high strength, toughness and self-lubrication at low temperatures[i]. The outstanding performance of PTFE in different environment makes it an attractive candidate for a variety of industrial applications, such as cookware, automotive, aerospace and medication.

IMPORTANCE OF FRICTION, WEAR & ADHESION FOR PTFE COATINGS

Specifically, the combination of super low COF, good wear resistance and chemical inertness at high temperatures leads to its application as a non-stick pan coating. In order to serve the purpose of further improving the mechanical properties in R&D as well as better controlling malfunction and consumption safety issues in Quality Control process, a reliable technique to quantitatively evaluate the tribo-mechanical properties of the PTFE coatings is in need. A controlled and known surface friction, wear and adhesion of the coatings is critical to ensure intended performance.

MEASUREMENT OBJECTIVE

In this application, the wear process of a PTFE coating for non-stick pan is simulated using Nanovea Tribometer in linear reciprocating mode. In addition, the Nanovea Mechanical Tester was used to perform a micro scratch adhesion test to determine the critical load of the coating adhesion failure.

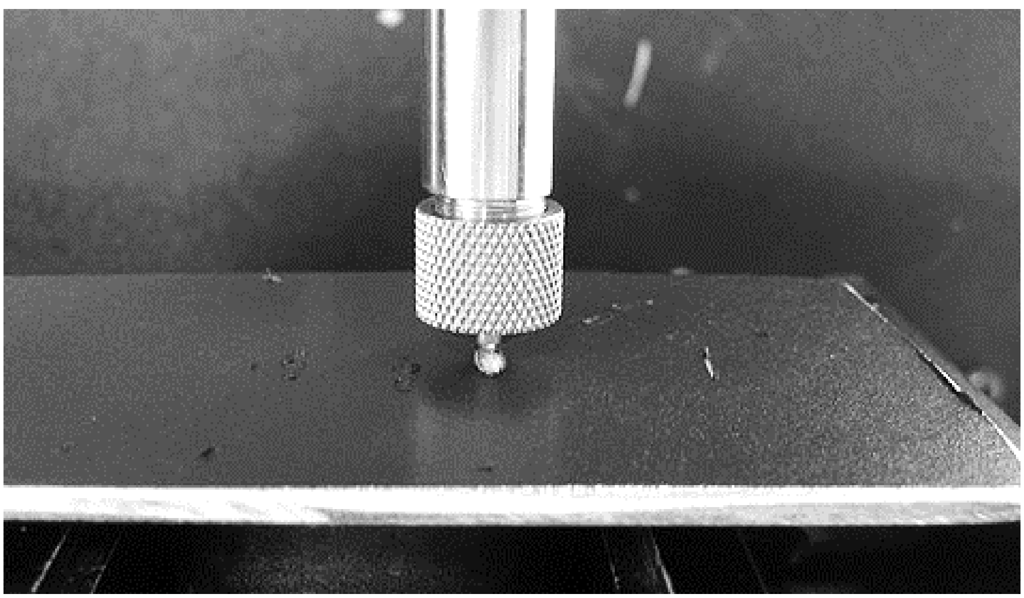

Fig. 1: Setup of linear reciprocating wear test using Nanovea Tribometer.

MEASUREMENT PRINCIPLE

Principle of linear wear test

The sample is mounted on a moving stage, while a known force is applied on a pin, or ball, in contact with the sample surface to create the wear. As the sample moves in a linear reciprocating (see Fig. 2) motion, the resulting frictional forces between the pin and the sample are measured using a strain gage sensor on the arm. The wear test is generally used as a comparative test to study the tribological properties of the materials. The coefficient of friction, COF, is recorded in situ. The volume loss allows calculating the wear rate of the material. Since the action performed on all samples is identical, the wear rate can be used as a quantitative comparative value for wear resistance. This simple method facilitates the determination and study of friction and wear behavior of almost every solid state material combination, with varying time, contact pressure, velocity, temperature, humidity, lubrication, etc.

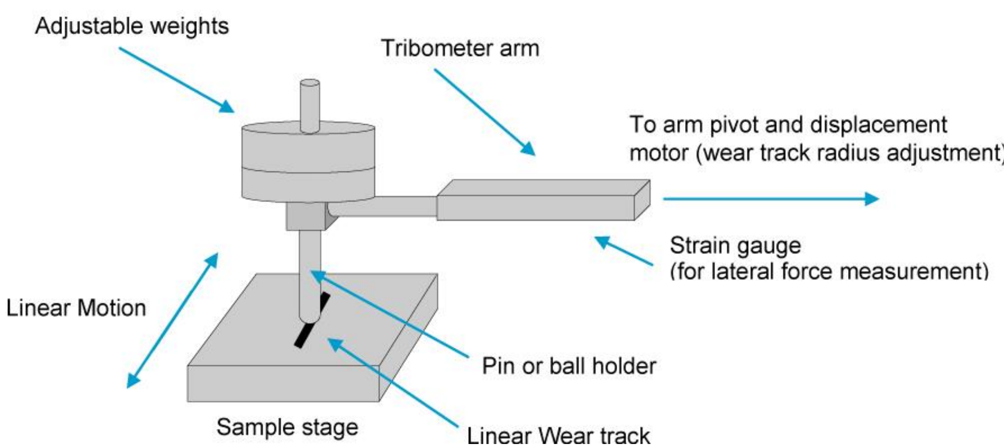

Fig. 2: Schematics of linear reciprocating wear test.

Principle of scratch test

The scratch testing method is a very reproducible quantitative technique. Critical loads at which failures appear are used to compare the cohesive or adhesive properties of coatings or bulk materials. During the test, scratches are made on the sample with a sphero-conical stylus (tip radius ranging from 1 to 200 μm) which is drawn at a constant speed across the sample, under a constant load, or, more commonly, a progressive load with a fixed loading rate. Sphero-conical stylus is available with different radii (which describes the "sharpness" of the stylus). Common radii are from 20 to 200 μm for micro/macro scratch tests, and 1 to 20 μm for nano scratch tests.

When performing a progressive load test, the critical load is defined as the smallest load at which a recognizable failure occurs. In the case of a constant load test, the critical load corresponds to the load at which a regular occurrence of such failure along the track is observed.

In the case of bulk materials, the critical loads observed are cohesive failures, such as cracking, or plastic deformation or the material. In the case of coated samples, the lower load regime results in conformal or tensile cracking of the coating which still remains fully adherent (which usually defines the first critical load). In the higher load regime, further damage usually comes from coating detachment from the substrate by spalling, buckling or chipping. Fig. 3 illustrates the principle of scratch testing.

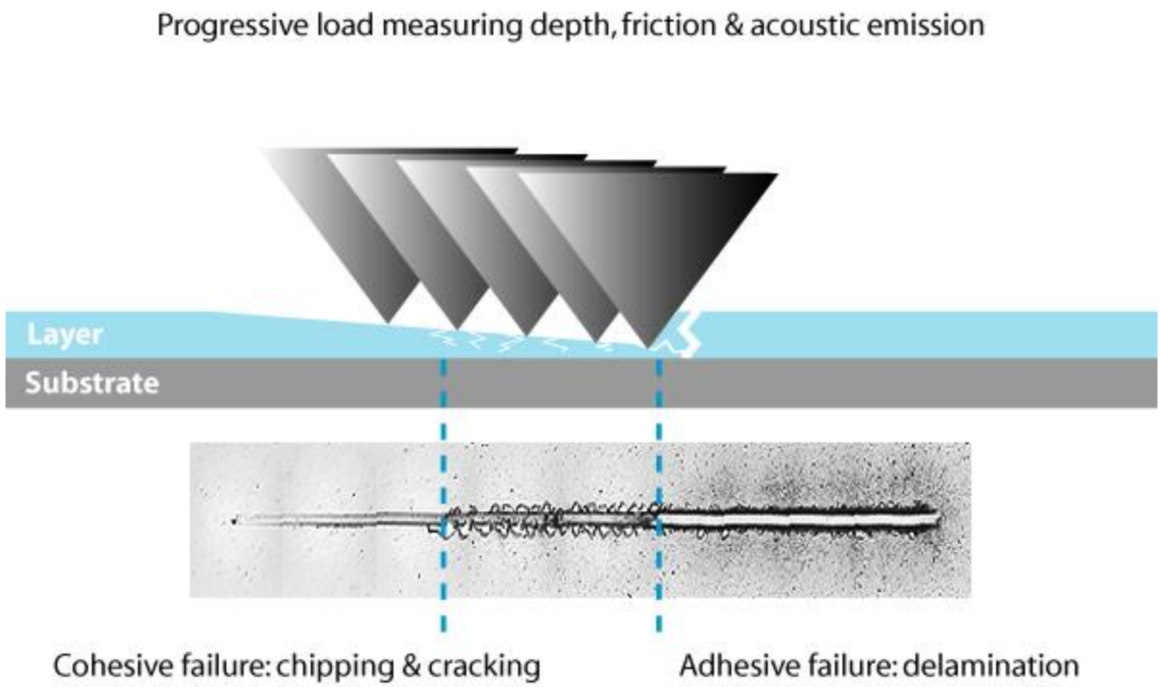

Fig. 3: Principle of scratch testing.

TEST PROCEDURE

Linear Reciprocating Wear Using Tribometer

The tribological behavior, e.g. COF and wear resistance of the PTFE coating sample was evaluated by Nanovea Tribometer using linear reciprocating mode. A Stainless Steel 440 ball tip (3 mm dia., Grade 100) was applied against the coating. The COF was monitored in situ. The test parameters are summarized in Table 1. The wear rate, *K*, was evaluated using the formula $K=V/(F\times s)=A/(F\times n)$, where *V* is the worn volume, *F* is the normal load, *s* is the sliding distance, *A* is the cross-sectional area of the wear track, and *n* is the number of strokes. Wear track profiles were evaluated by the Nanovea Optical Profilometer, and the wear track morphology was examined using optical microscope.

Load	30 N
Duration of test	5 min
Sliding rate	80 rpm
Amplitude of track	8 mm
Revolutions	300
Ball Diameter	3 mm
Ball Material	Stainless Steel 440
Lubricant	None
Atmosphere	Air
Temperature	23°C (room)
Humidity	43%

Table 1: Wear test conditions.

Micro Scratch Adhesion Test

The scratch resistance of the lenses were tested using Micro Scratch Mode with a diamond stylus. Three tests were repeated at the same testing conditions to ensure reproducibility of the results. The test parameters are listed in Table 2.

Load type	Progressive
Initial Load	0.1mN
Final Load	20 mN
Loading rate	40 mN/min
Scratch Length	3mm
Scratching speed, dx/dt	6.0 mm/min
Indenter geometry	120° Rockwell C
Indenter material (tip)	Diamond
Indenter tip radius	200 µm

Table 2: Test conditions of scratch adhesion measurement.

RESULTS AND DISCUSSION

Linear Reciprocating Wear Test

The COF recorded in situ is shown in Fig. 4. The test sample exhibited COF of ~0.18 in the first 130 revolutions, due to the low stickiness of PTFE; however, this is followed by abrupt increase of COF to ~1 upon breakthrough of the coating and exposure of the substrate underneath. The wear track profile after the linear reciprocating tests was measured using Nanovea non-contact optical profilometer as shown in Fig. 5. The corresponding wear rate and wear track depth were calculated to be ~2.78 $\times$ 10^{-3} mm^3/N m and 44.94 µm, respectively.

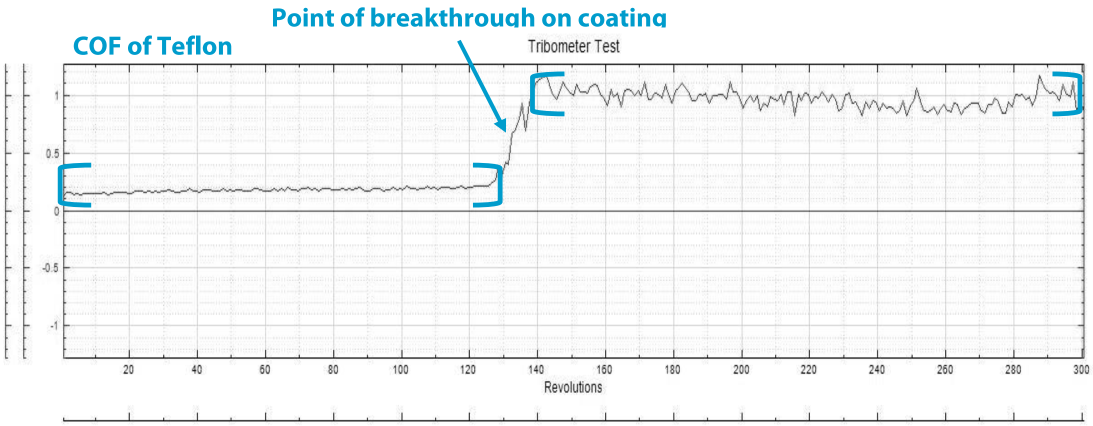

Fig. 4: Evolution of COF of PTFE coating during wear.

PTFE Before breakthrough	
Max COF	0.217
Min COF	0.125
Average COF	0.177
PTFE After Breakthrough	
Max COF	1.174
Min COF	0.818
Average COF	0.971

Table 3: COF before and after breakthrough during the wear test.

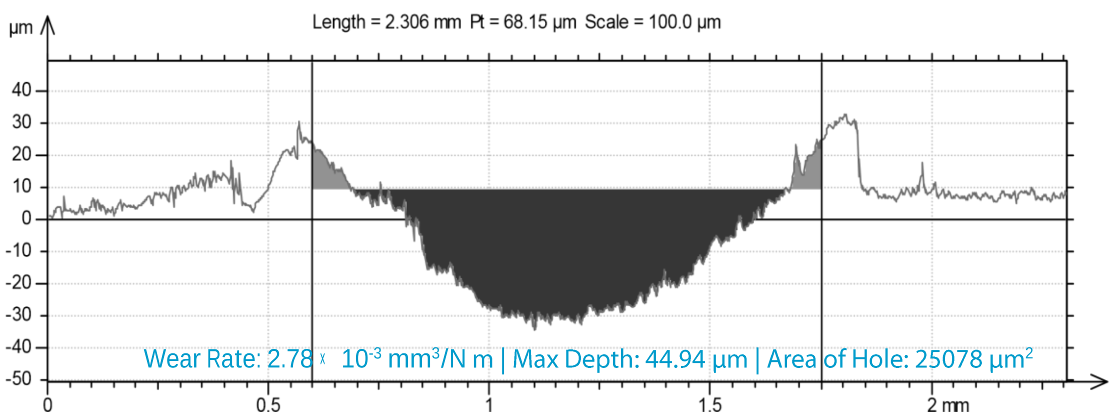

Fig. 5: Profile extraction of wear track – PTFE.

Micro Scratch Adhesion Test

The adhesion of the PTFE coating to the substrate is measured using scratch tests with a 200 µm diamond stylus. The micrograph is shown in Fig. 6 and Fig. 7, Evolution of COF and penetration depth in Fig. 8 and the results are summarized in Table 4. When the diamond stylus progressively penetrated into the coating as the load linearly increased, the COF increases as well. When a load of ~8.5 N was reached, breakthrough of the coating and exposure of the substrate occurred under the high pressure, leading to a high COF of ~0.3. The low St Dev in Table 4 demonstrates the repeatability of the scratch test using Nanovea Mechanical Tester.

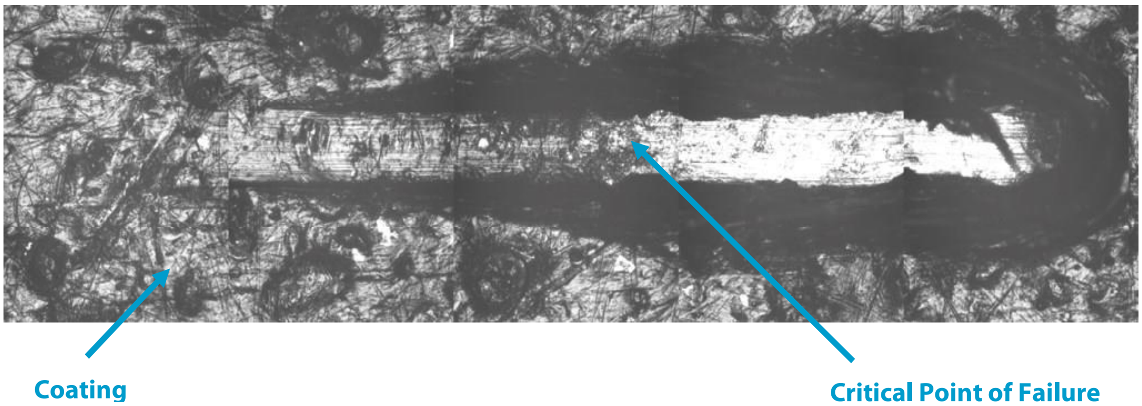

Fig. 6: Micrograph of full scratch on PTFE (10X).

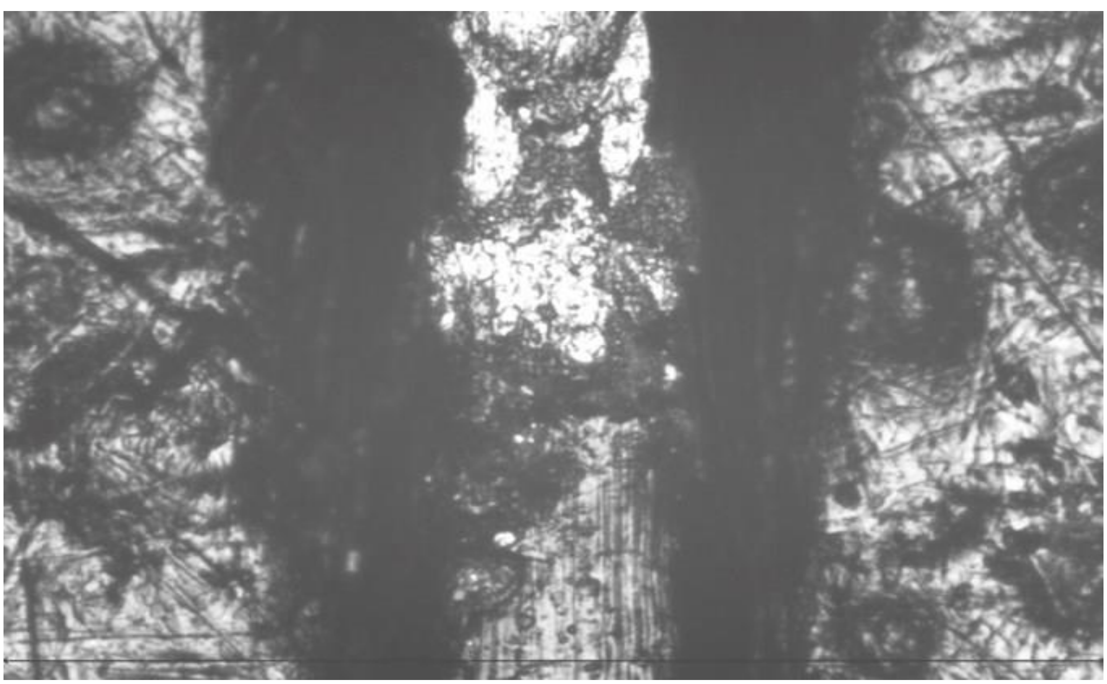

Fig. 7: Microscope image of Critical point of failure for PTFE.

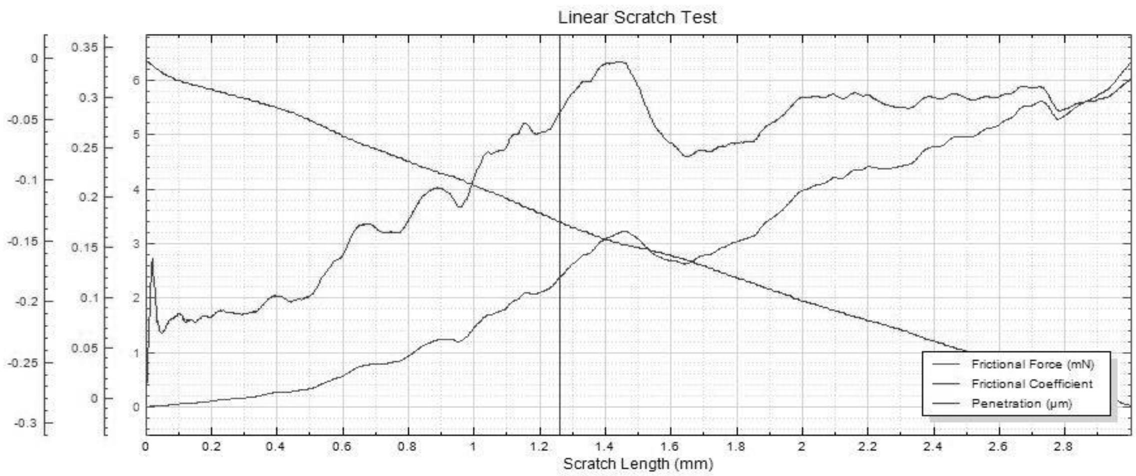

Fig. 8: Friction graph showing line of critical point of failure - PTFE.

Scratch	Point of Failure [N]	Frictional Force [N]	COF
1	8.34	2.37	0.285
2	8.60	2.66	0.310
3	8.62	2.39	0.295
Average	8.52	2.47	0.297
St dev	0.17	0.16	0.012

Table 4: The summary of Critical Load, Frictional Force and COF during scratch test.

CONCLUSION

In this study, we simulated the wear process of a PTFE coating for non-stick pan using Nanovea Tribometer in linear reciprocating mode. The PTFE coating exhibited a low COF of ~0.18 until breakthrough of the coating taking place at ~130 revolutions. The adhesion of the PTFE coating to the metal substrate was quantitatively determined using the Nanovea Mechanical Tester – the critical load of the coating adhesion failure is ~8.5 N in this test.

Nanovea Tribometer offers precise and repeatable wear and friction testing using ISO and ASTM compliant rotative and linear modes. It provides optional high temperature wear, lubrication and tribocorrosion modules available in one pre-integrated system. Such versatility allows users to better simulate the real application environment and improve fundamental understanding of the wear mechanism and tribological characteristics of various materials. The Nano, Micro or Macro modules of the Nanovea Mechanical Tester all include ISO and ASTM compliant indentation, scratch and wear tester modes, providing the widest and most user friendly range of testing available in a single system.

Optional 3D non-contact profiler is available for high resolution 3D imaging of wear track in addition to other surface measurements such as roughness.

Learn More about the Nanovea Tribometer, Nanovea Mechanical Tester and Lab Service

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[i] http://www2.dupont.com/Teflon_Industrial/en_US/tech_info/techinfo_compare.html