INDUSTRIAL COATIN

SCRATCH AND WEAR EVALUATION USING A TRIBON

Prepared by

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INTRODUCTION

Acrylic urethane paint is a type of fast-dry protective coating widely used in a variety of industrial applications, such as floor paint, auto paint, and others. When used as floor paint, it can serve areas with heavy foot and rubber-wheel traffic, such as walkways, curbs and parking lots.

IMPORTANCE OF SCRATCH AND WEAR TESTING FOR QUALITY CONTROL

Traditionally, Taber abrasion tests were carried out to evaluate the wear resistance of acrylic urethane floor paint according to the ASTM D4060 standard. However, as mentioned in the standard, "For some materials, abrasion tests utilizing the Taber Abraser may be subject to variation due to changes in the abrasive characteristics of the wheel during testing."[1] This may result in poor reproducibility of test results and create difficulty in comparing values reported from different laboratories. Moreover, in Taber abrasion tests, abrasion resistance is calculated as loss in weight at a specified number of abrasion cycles. However, acrylic urethane floor paints have a recommended dry film thickness of 37.5-50 μm[2].

The aggressive abrasion process by Taber Abraser can quickly wear through the acrylic urethane coating and create mass loss to the substrate leading to substantial errors in the calculation of the paint weight loss. The implant of abrasive particles in the paint during the abrasion test also contributes to errors. Therefore, a well-controlled quantifiable and reliable measurement is crucial to ensure reproducible wear evaluation of the paint. In addition, the scratch test allows users to detect premature adhesive/cohesive failures in real-life applications.

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[1] Wredenberg, Fredrik; PL Larsson (2009). "Scratch testing of metals and polymers: Experiments and numerics". Wear 266 (1 2): 76.

[2] Encyclopæ dia Britannica. 2009. Encyclopæ dia Britannica Online. 22 Feb. 2009 "Mohs hardness."

MEASUREMENT OBJECTIVE

In this study, we showcase that **NANOVEA** Tribometers and Mechanical Testers are ideal for evaluation and quality control of industrial coatings.

The wear process of acrylic urethane floor paints with different topcoats is simulated in a controlled and monitored manner using the **NANOVEA** Tribometer. Micro scratch testing is used to measure the load required to cause cohesive or adhesive failure to the paint.

NANOVEA T100

The Compact Pneumatic Tribometer

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ABOUT THE INSTRUMENT

NANOVEA PB1000

The Large Platform Mechanical Tester

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TEST PROCEDURE

This study evaluates four commercially available water-based acrylic floor coatings that have the same primer (basecoat) and different topcoats of the same formula with a small alternation in the additive blends for the purpose of enhancing durability. These four coatings are identified as *Samples A*, *B*, *C* and *D*.
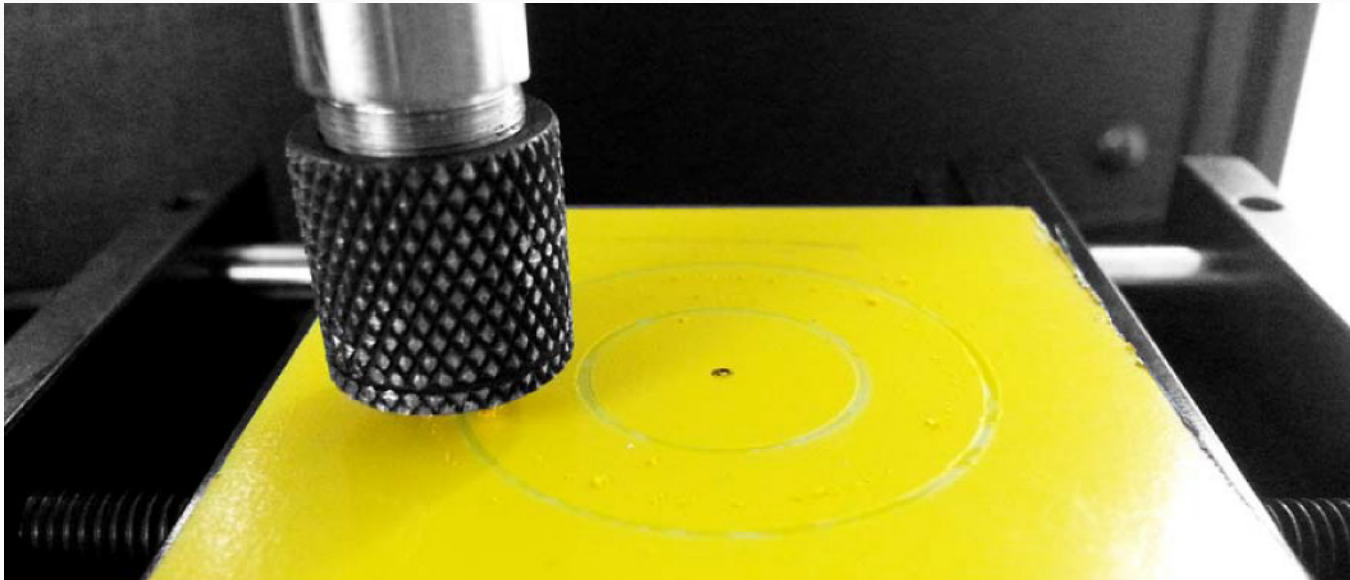
WEAR TEST

The **NANOVEA** Tribometer was applied to evaluate the tribological behavior, e.g. coefficient of friction, COF, and wear resistance. A SS440 ball tip (6 mm dia., Grade 100) was applied against the tested paints. The COF was recorded in situ. 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 revolution. Surface roughness and wear track profiles were evaluated by the **NANOVEA** Optical Profilometer, and the wear track morphology was examined using optical microscope.

WEAR TEST PARAMETERS

NORMAL FORCE

20 N

SPEED

15 m/min

DURATION OF TEST

100, 150, 300 & 800 cycles

SCRATCH TEST

The **NANOVEA** Mechanical Tester equipped with a Rockwell C diamond stylus (200 μm radius) was used to perform progressive load scratch tests on the paint samples using the Micro Scratch Tester Mode. Two final loads were used: 5 N final load for investigating paint delamination from the primer, and 35 N for investigating primer delamination from the metal substrates. Three tests were repeated at the same testing conditions on each sample to ensure reproducibility of the results.

Panoramic images of the whole scratch lengths were automatically generated and their critical failure locations were correlated with the applied loads by the system software. This software feature facilitates users to perform analysis on the scratch tracks any time, rather than having to determine the critical load under the microscope immediately after the scratch tests.

SCRATCH TEST PARAMETERS

LOAD TYPE .... *Progressive*

INITIAL LOAD .... *0.01 mN*

FINAL LOAD .... *5 N / 35 N*

LOADING RATE .... *10 / 70 N/min*

SCRATCH LENGTH .... *3 mm*

SCRATCHING SPEED, dx/dt .... *6.0 mm/min*

INDENTER GEOMETRY .... *120° cone*

INDENTER MATERIAL (tip) .... *Diamond*

INDENTER TIP RADIUS .... *200 μm*

WEAR TEST RESULTS

Four pin-on-disk wear tests at different number of revolutions (100, 150, 300 and 800 cycles) were performed on each sample in order to monitor the evolution of wear. The surface morphology of the samples were measured with a **NANOVEA** 3D Non-Contact Profiler to quantify the surface roughness prior to conducting wear testing. All samples had a comparable surface roughness of approximately 1 μm as displayed in **FIGURE 1**. The COF was recorded in situ during the wear tests as shown in **FIGURE 2**. **FIGURE 4** presents the evolution of wear tracks after 100, 150, 300 and 800 cycles, and **FIGURE 3** summarized the average wear rate of different samples at different stages of the wear process.

Compared with a COF value of ~0.07 for the other three samples, **Sample A** exhibits a much higher COF of ~0.15 at the beginning, which gradually increases and gets stable at ~0.3 after 300 wear cycles. Such a high COF accelerates the wear process and creates a substantial amount of paint debris as indicated in **FIGURE 4** – the topcoat of **Sample A** has started to be removed in the first 100 revolutions. As shown in **FIGURE 3**, **Sample A** exhibits the highest wear rate of ~5 μm²/N in the first 300 cycles, which slightly decreases to ~3.5 μm²/N due to the better wear resistance of the metal substrate. The topcoat of **Sample C** starts to fail after 150 wear cycles as shown in **FIGURE 4**, which is also indicated by the increase of COF in **FIGURE 2**.

In comparison, **Sample B** and **Sample D** show enhanced tribological properties. **Sample B** maintains a low COF throughout the whole test – the COF slightly increases from~0.05 to ~0.1. Such a lubricating effect substantially enhances its wear resistance – the topcoat still provides superior protection to the primer underneath after 800 wear cycles. The lowest average wear rate of only ~0.77 µm²/N is measured for **Sample B** at 800 cycles. The topcoat of **Sample D** starts to delaminate after 375 cycles, as reflected by the abrupt increase of COF in **FIGURE 2**. The average wear rate of **Sample D** is ~1.1 µm²/N at 800 cycles.

Compared to the conventional Taber abrasion measurements, **NANOVEA** Tribometer provides well-controlled quantifiable and reliable wear assessments that ensure reproducible evaluations and quality control of commercial floor/auto paints. Moreover, the capacity of in situ COF measurements allow users to correlate the different stages of a wear process with the evolution of COF, which is critical in improving fundamental understanding of the wear mechanism and tribological characteristics of various paint coatings.

Sample A R = 1.14 μm **Sample B** R = 1.08 μm **Sample C** R = 0.93 μm **Sample D** R = 1.05 μm
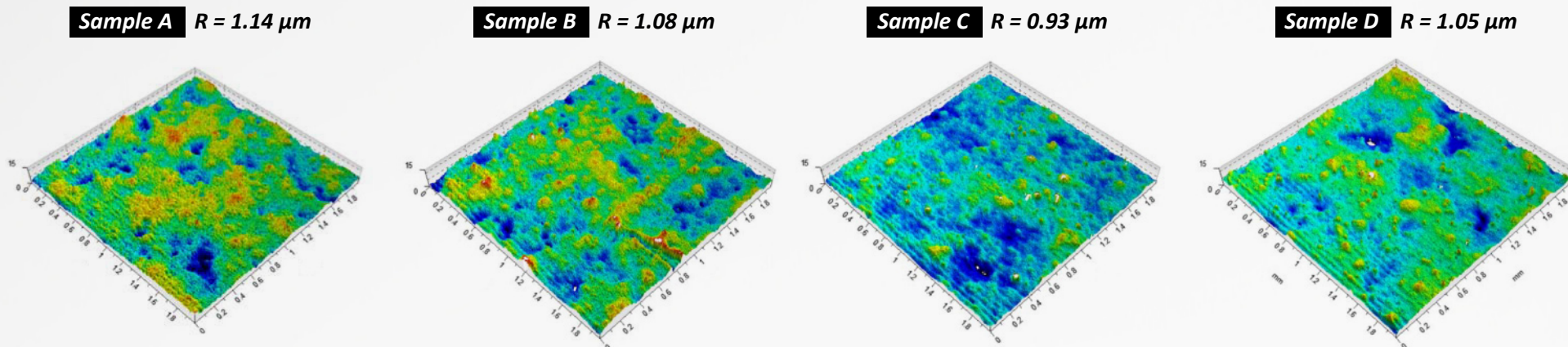
FIGURE 1: **3D morphology and roughness of the paint samples.**
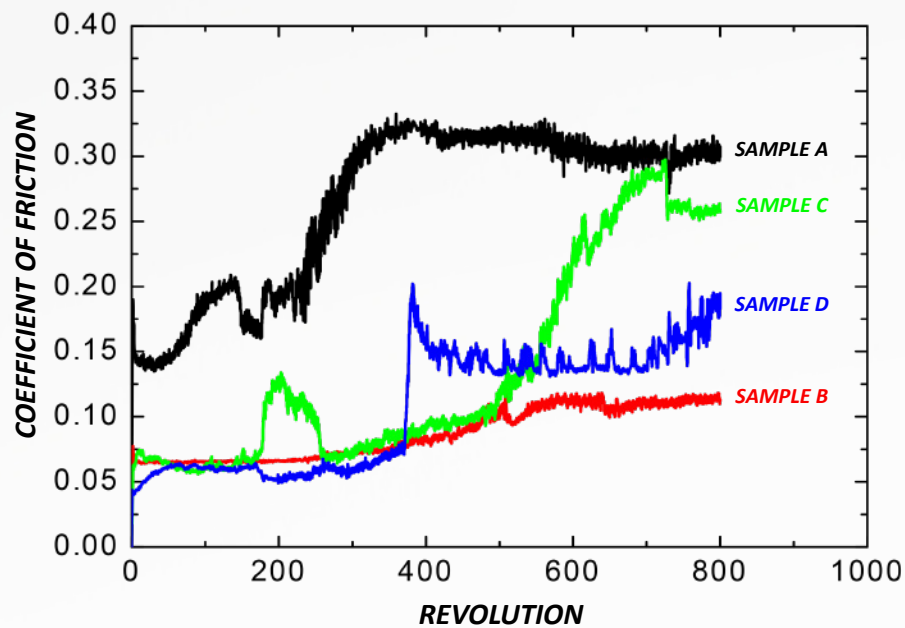
FIGURE 2: **COF during pin-on-disk tests.**
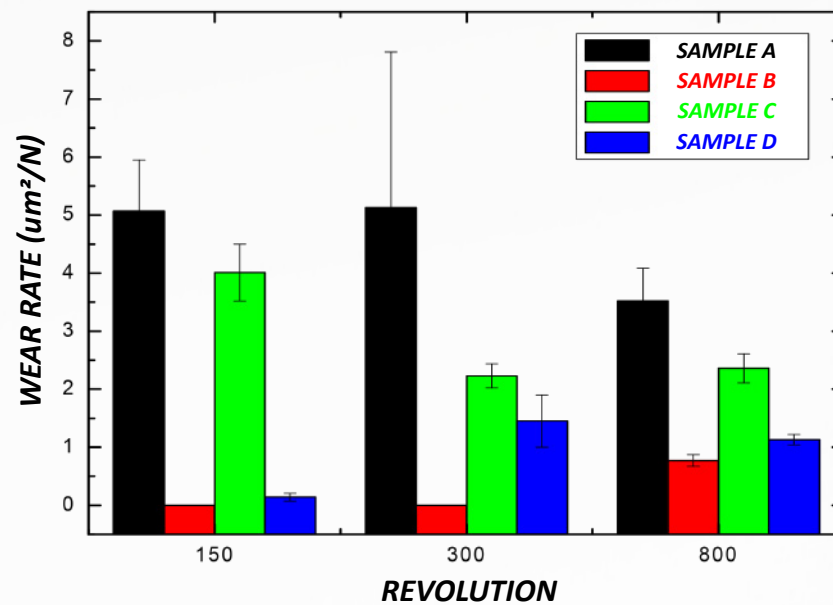
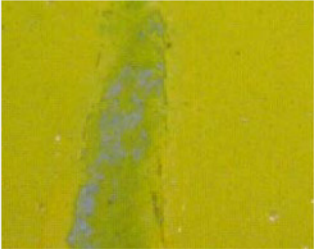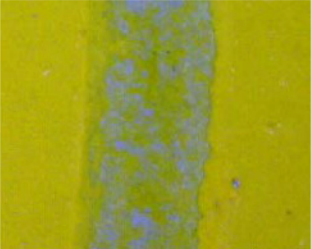**FIGURE 3:** **Evolution of wear rate of different paints.**
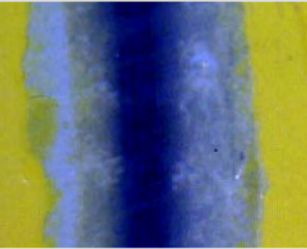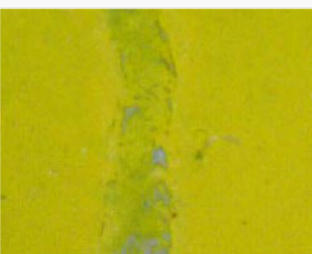
FIGURE 4: *Evolution of wear tracks during the pin-on-disk tests.*

SCRATCH TEST RESULTS

FIGURE 5 shows the plot of normal force, frictional force and true depth as a function of scratch length for **Sample A** as an example. An optional acoustic emission module can be installed to provide more information. As the normal load linearly increases, the indenter tip gradually sinks into the tested sample as reflected by the progressive increase of true depth. The variation in the slopes of frictional force and true depth curves can be used as one of the implications that coating failures start to occur.
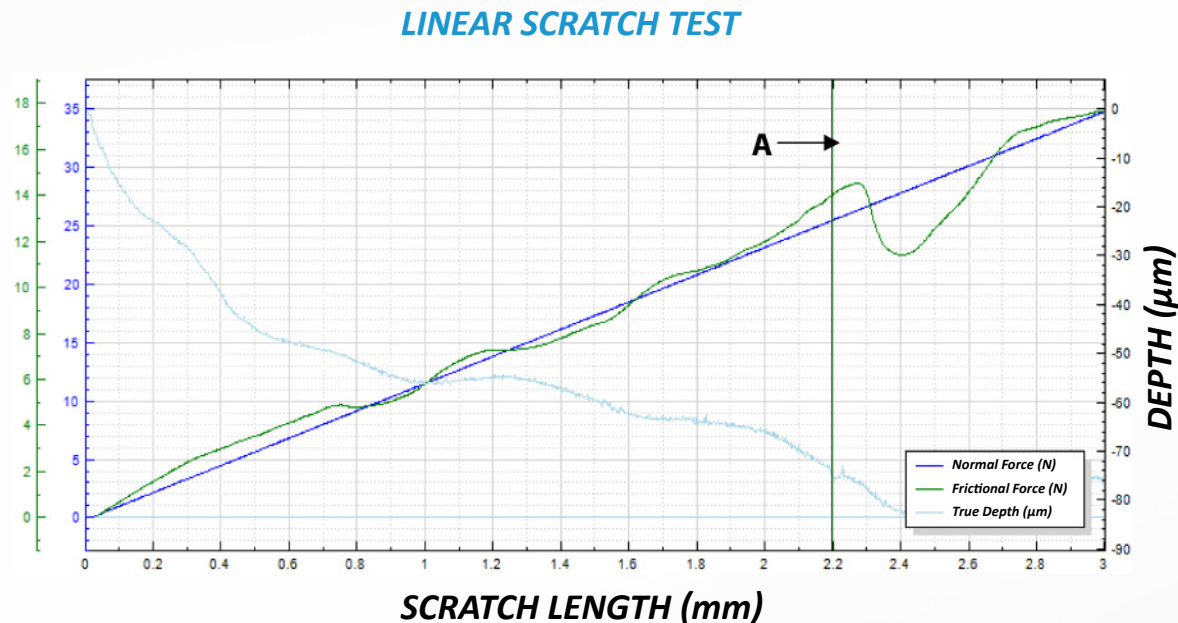

FIGURE 5: *Normal force, frictional force and true depth as a function of scratch length for scratch test of Sample A with a maximum load of 5 N.*

FIGURE 6 and FIGURE 7 show the full scratches of all four paint samples tested with a maximum load of 5 N and 35 N, respectively. **Sample D** required a higher load of 50 N to delaminate the primer. Scratch tests at 5 N final load (**FIGURE 6**) evaluate the cohesive/adhesive failure of the top paint, while the ones at 35 N (**FIGURE 7**) assess the delamination of the primer. The arrows in the micrographs indicate the point at which the top coating or the primer start to be completely removed from the primer or the substrate. The load at this point, so called Critical Load, **Lc**, is used to compare the cohesive or adhesive properties of the paint as summarized in **Table 1**.

It is evident that the paint **Sample D** has the best interfacial adhesion – exhibiting the highest **Lc** values of 4.04 N at paint delamination and 36.61 N at primer delamination. **Sample B** shows the second best scratch resistance. From the scratch analysis, we show that optimization of the paint formula is critical to the mechanical behaviors, or more specifically, scratch resistance and adhesion property of acrylic floor paints.

	PAINT DELAMINATION (N)				PRIMER DELAMINATION (N)			
	Test 1	Test 2	Test 3	*Average*	Test 1	Test 2	Test 3	*Average*
SAMPLE A	3.01	3.21	3.27	3.16 ± 0.14	25.55	25.44	25.21	25.40 ± 0.17
SAMPLE B	3.45	3.36	3.53	3.45 ± 0.08	27.58	27.80	28.62	28.00 ± 0.55
SAMPLE C	1.61	1.09	1.57	1.42 ± 0.29	22.91	24.02	24.25	23.73 ± 0.72
SAMPLE D	3.94	4.02	4.17	4.04 ± 0.12	37.98	36.08	35.77	36.61 ± 1.20

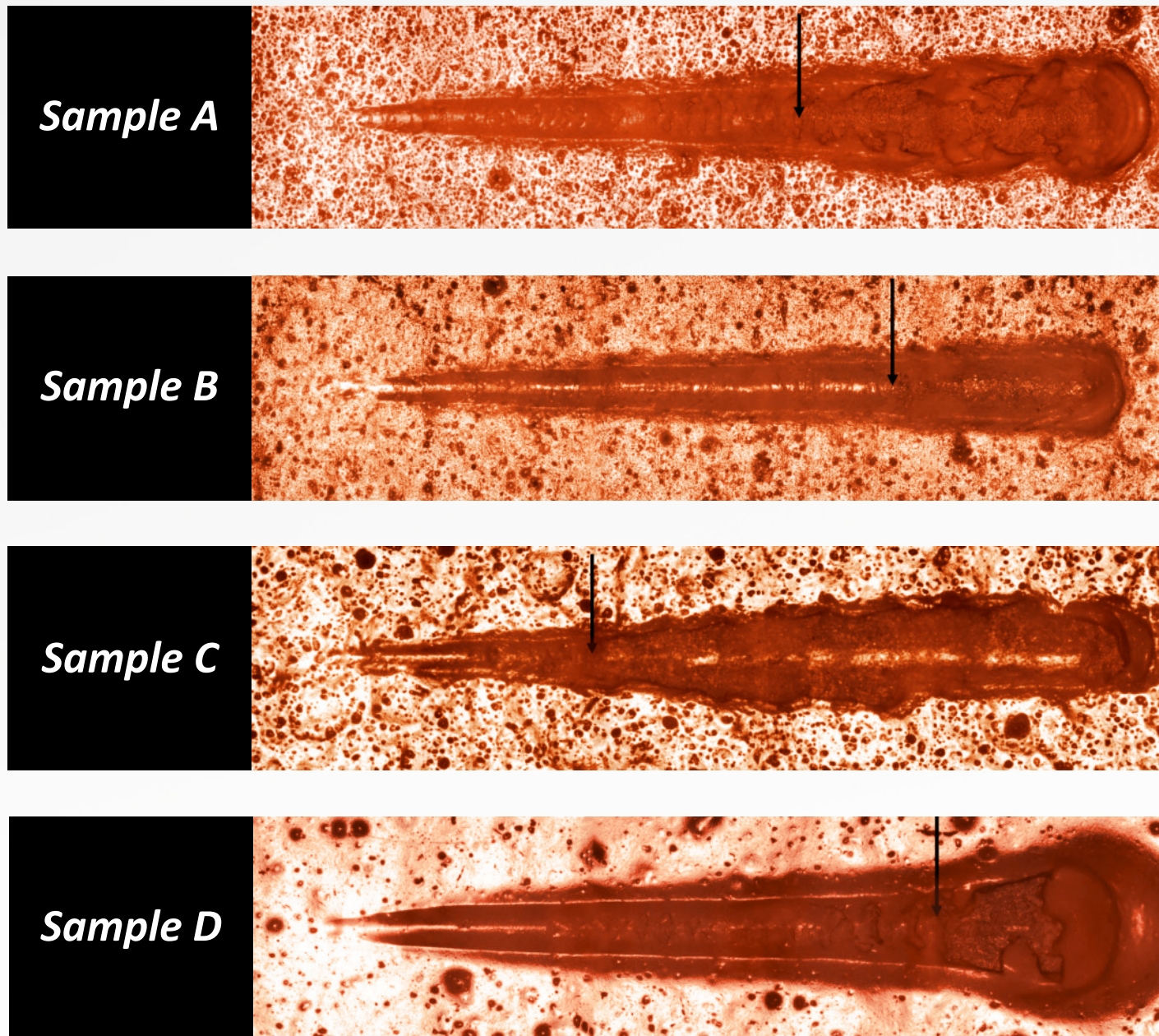**TABLE 1: Summary of critical loads.**

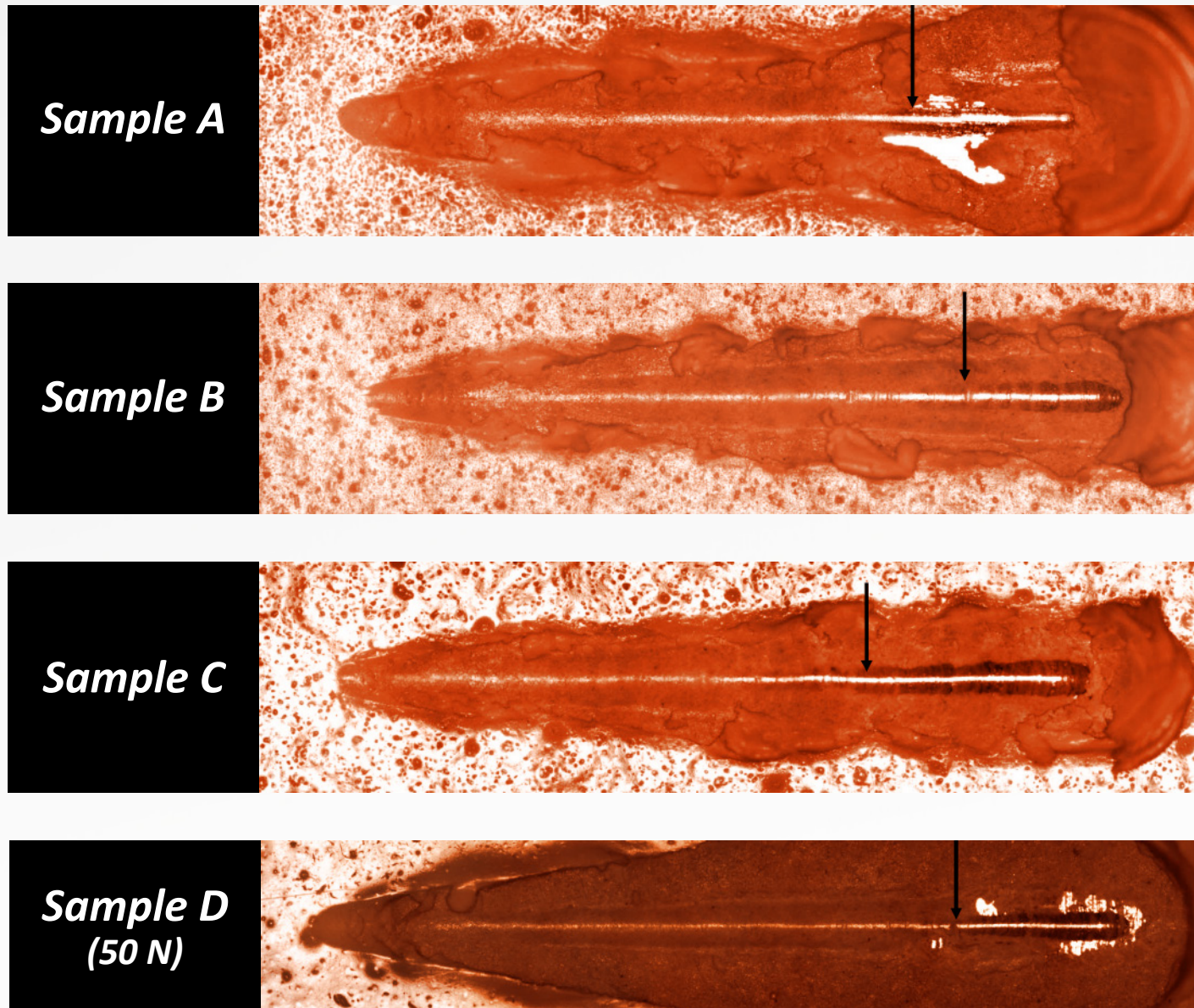**FIGURE 6:** *Micrographs of full scratch with 5 N maximum load.*

FIGURE 7: *Micrographs of full scratch with 35 N maximum load.*

CONCLUSION

Compared to the conventional Taber abrasion measurements, the **NANOVEA** Mechanical Tester and Tribometer are superior tools for evaluation and quality control of commercial floor and automotive coatings. The **NANOVEA** Mechanical Tester in Scratch mode can detect adhesion/cohesion problems in a coating system. The **NANOVEA** Tribometer provides well-controlled quantifiable and repeatable tribological analysis on wear resistance and coefficient of friction of the paints.

Based on the comprehensive tribological and mechanical analyses on the water based acrylic floor coatings tested in this study, we show that **Sample B** possesses the lowest COF and wear rate and the second best scratch resistance, while **Sample D** exhibits the best scratch resistance and second best wear resistance. This assessment allows us to evaluate and select the best candidate targeting the needs in different application environments.

The Nano and Micro modules of the **NANOVEA** Mechanical Tester all include ISO and ASTM compliant indentation, scratch and wear tester modes, providing the widest range of testing available for paint evaluation on a single module. The **NANOVEA** Tribometer offers precise and repeatable wear and friction testing using ISO and ASTM compliant rotative and linear modes, with optional high temperature wear, lubrication and tribo-corrosion modules available in one pre-integrated system. **NANOVEA**'s unmatched range is an ideal solution for determining the full range of mechanical/tribological properties of thin or thick, soft or hard coatings, films and substrates, including hardness, Young's modulus, fracture toughness, adhesion, wear resistance and many others. Optional **NANOVEA** Non-Contact Optical Profilers are available for high resolution 3D imaging of scratchs and wear tracks in addition to other surface measurements such as roughness.

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