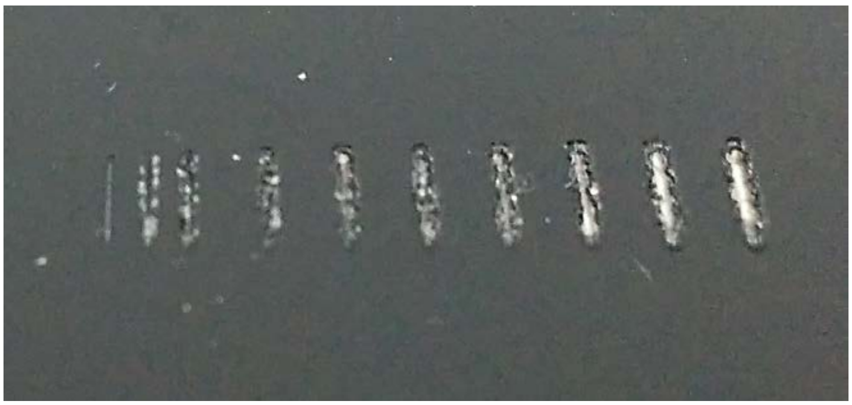
CORROSION RESISTANCE OF COATING AFTER SCRATCH TESTING



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INTRODUCTION

Corrosion resistant coatings protect metal parts against corrosion caused by various harsh environments or chemicals, such as moisture, salt spray, oxidation and acids. They protect metal surfaces by acting as a barrier to inhibit the contact of corrosive media. Targeting the performance requirements of specific applications, there are a number of different corrosion resistant coatings available on the markets, including but not limited to epoxy, fluoropolymer, phosphate, PTFE[i].

The corrosion resistant coatings should possess sufficient mechanical strength as they are often exposed to abrasive and erosive application environments. For example, the abrasive oil sands constantly wear away the inside of pipe, which progressively compromise the pipe's integrity and potentially result in failure. In auto industry, corrosion takes place at the location of scratches on the auto paint, especially during freezing winter when salts are applied on road. Therefore, a quantitative and reliable tool for measuring the influence of scratches on protective coatings and its corrosion resistance is in need, in order to select the most proper coating for the intended application.

MEASUREMENT OBJECTIVE

In this study, the Nanovea Mechanical Tester was used to generate scratches at different constant loads on a coated steel sheet. This was followed by corrosion tests to determine the critical load at which the corrosion resistant coating failed to protect the metal substrate. We would like to showcase that Nanovea Mechanical Tester in combination with the corrosion test is an ideal tool for quantitatively evaluating the performance of protective coating used for abrasion and corrosion protection.

Fig. 1: Non-contact profilometer sensor scanning on the scratched sample.

TEST CONDITIONS

The Macro Scratch Module of the Nanovea Mechanical Tester was employed to perform the scratch tests on a coated steel sheet. A conical diamond stylus of apex angle 120° with tip radius of 200 µm scratches in the surface of a coated steel sheet sample along a linear path under a constant normal force with a constant speed. The evolution of coefficient of friction (COF) and true depth were recorded in situ during the scratch hardness test. The test parameters are summarized in Table 1.

Test parameters	Value
Normal force (N)	5, 10, 15, 20, 25, 30, 35, 40, 50, 75, 100
Sliding speed (mm/min)	6
Sliding distance (mm)	3
Atmosphere	Air
Temperature	24°C (room)

Table 1: Test parameters of the scratch measurement.

After the scratch test, the coated steel sample was immersed and corroded in the 125 g/L Hydrochloric Acid (HCl) for 3 hours as shown in Fig. 2, in order to investigate the effect of scratches of the coated metal surface on its corrosion resistance. The 3D profile of the scratch tracks before and after the corrosion test was measured using Nanovea Noncontact Optical Profilometer.

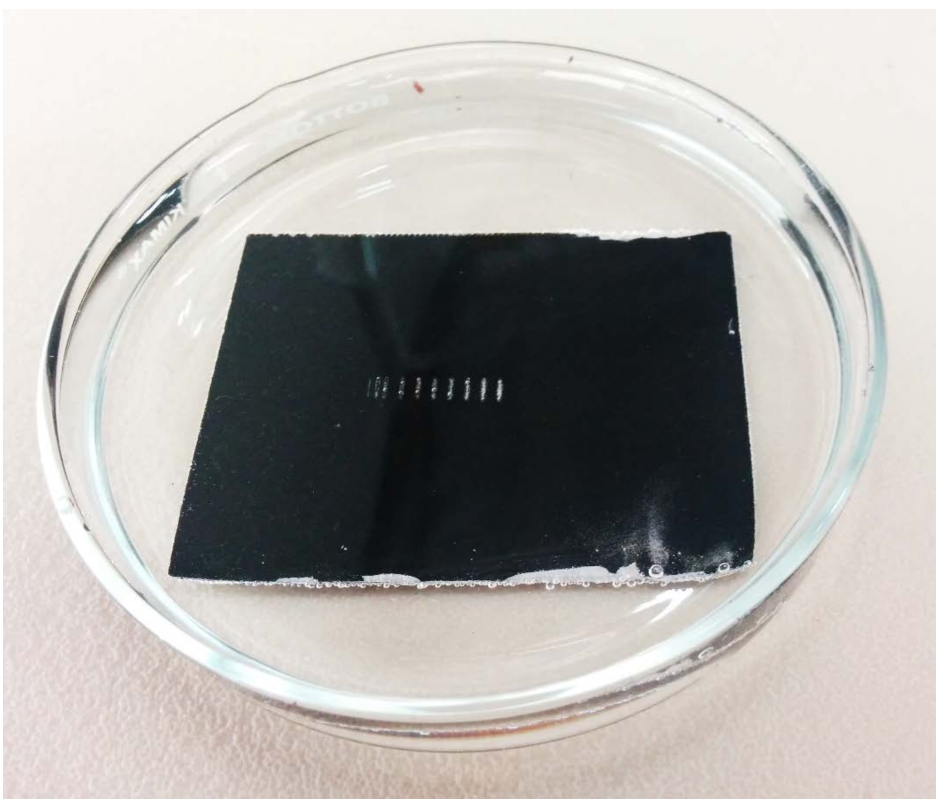


Fig. 2: Immersion of the coated Steel sample in the HCl solution.

RESULTS AND DISCUSSION

The images of the scratch tracks on the coated steel surface tested at different loads are shown in Fig. 3. The scratches possess progressively increased volume as the constant normal load increases from 5 N to 100 N. The evolution of COF and true depth of the coated steel sample at 5 and 100 N are shown in Fig. 6 as examples. The coating shows a low COF and depth of ~0.3 and 22 µm, respectively at 5 N, compared to ~0.55 and 130 µm for that at 100 N. Such information provides insight of mechanical failures taking place during scratching, enabling users to detect mechanical defects and further investigate the scratch behavior of the tested material.

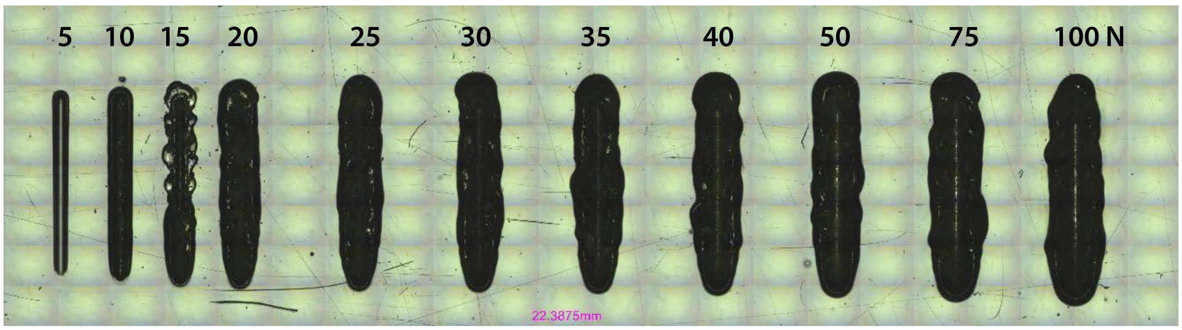
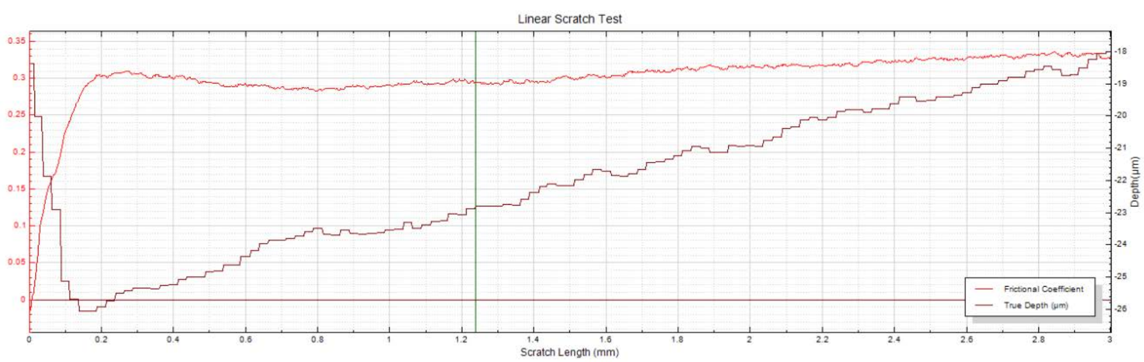


Fig. 3: Scratch tracks under the microscope after the scratch test.

(a) At 5 N:



(b) At 100 N:

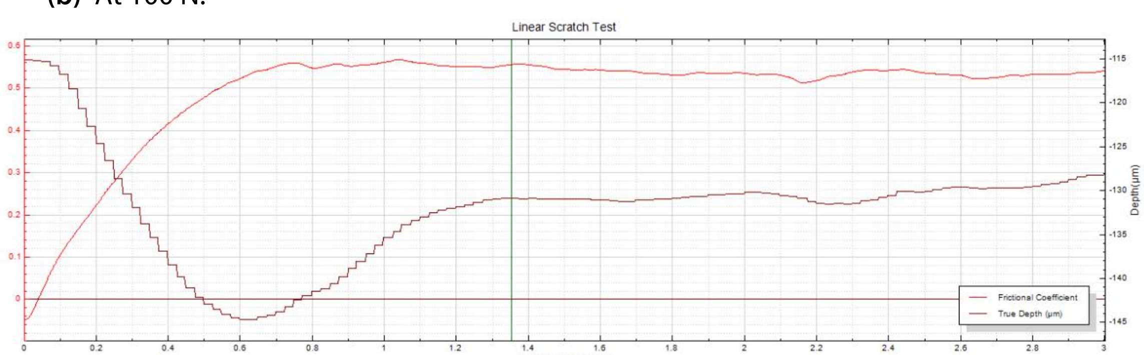
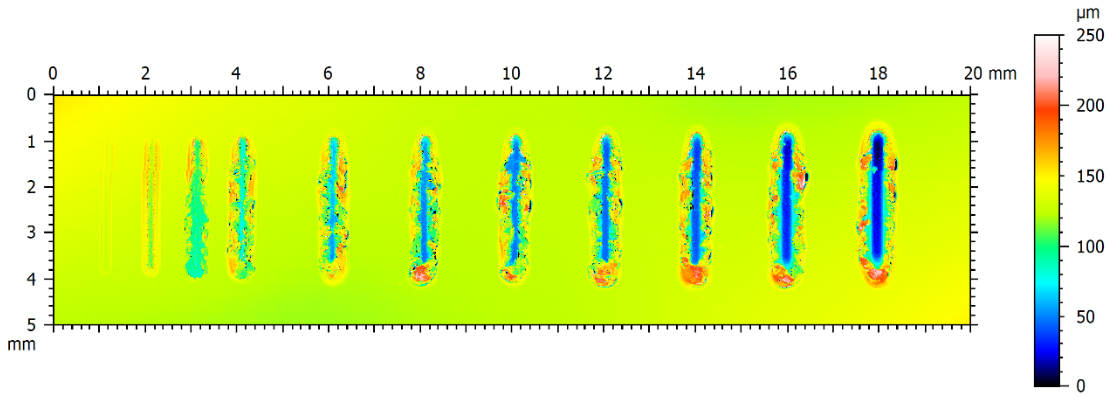


Fig. 4: The evolution of COF and true depth of the coated steel sample at 5 and 100 N.

The 3D profiles of the scratch tracks before and after the corrosion test are compared in Fig. 5, and the calculated scratch track volumes are summarized in Fig. 6. It is evident that the scratch tracks created at loads below 20 N exhibit comparable volume before and after the corrosion test. However, the volume of the scratch tracks generated at loads higher than 25 N increases substantially in the corrosion test, indicating the failure of the polymer coating and exposure of the metal substrate during the scratch tests at loads above 25 N.

The scratch tests at different constant loads in combination with the corrosion test provides a quantitative testing tool for evaluating the coating's scratch and corrosion resistance with good precision and repeatability. It is useful for quality control and development of new protective coatings or paints for corrosion protection.

(a) Before Corrosion:



(b) After Corrosion:

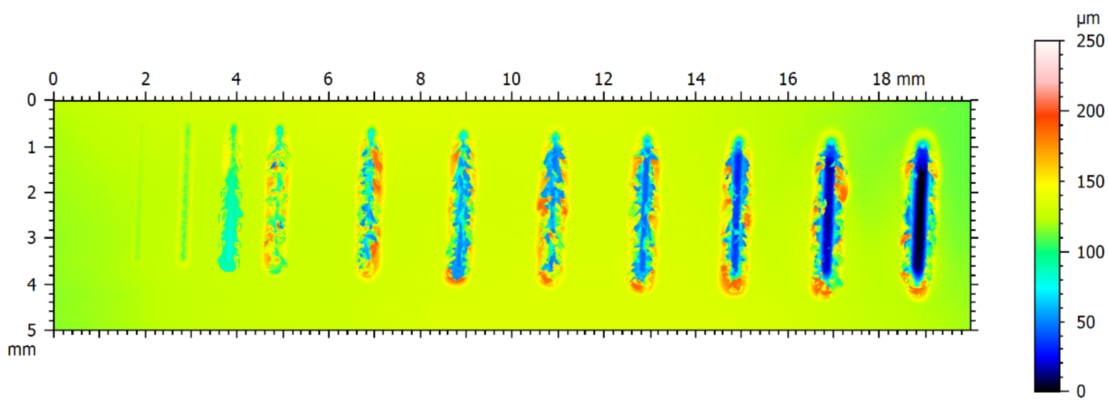


Fig. 5: 3D profile of the scratch tracks before and after the corrosion test.

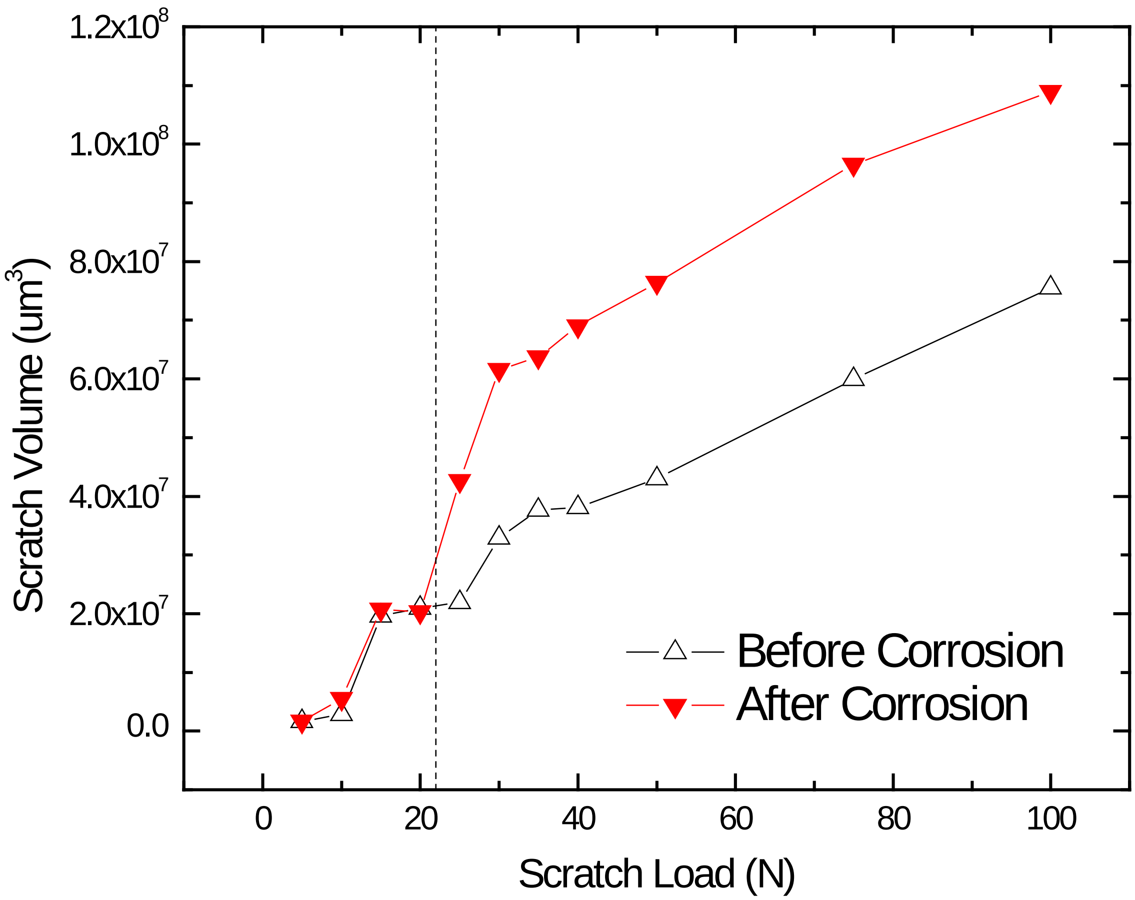


Fig. 6: The comparison of the volume of the scratches before and after the corrosion tests in HCl solution.

CONCLUSION

In this study, we showcased the capacity of Nanovea Mechanical Tester in performing macro scratch tests at different constant loads. Combing with the corrosion test, the scratch test at constant loads provides a tool for quantitatively assessing the scratch and corrosion resistance of protective coatings. In addition, Nanovea Mechanical Tester monitors the evolution of coefficient of friction, acoustic emission and true depth during the scratch tests. The Nanovea non-contact optical profilometer can precisely measure the scratch track volume.

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. Nanovea's unmatched range is an ideal solution for determining the full range of mechanical 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.

To learn more about [Nanovea Mechanical Tester] or [Lab Services].

APPENDIX: MEASUREMENT PRINCIPLE

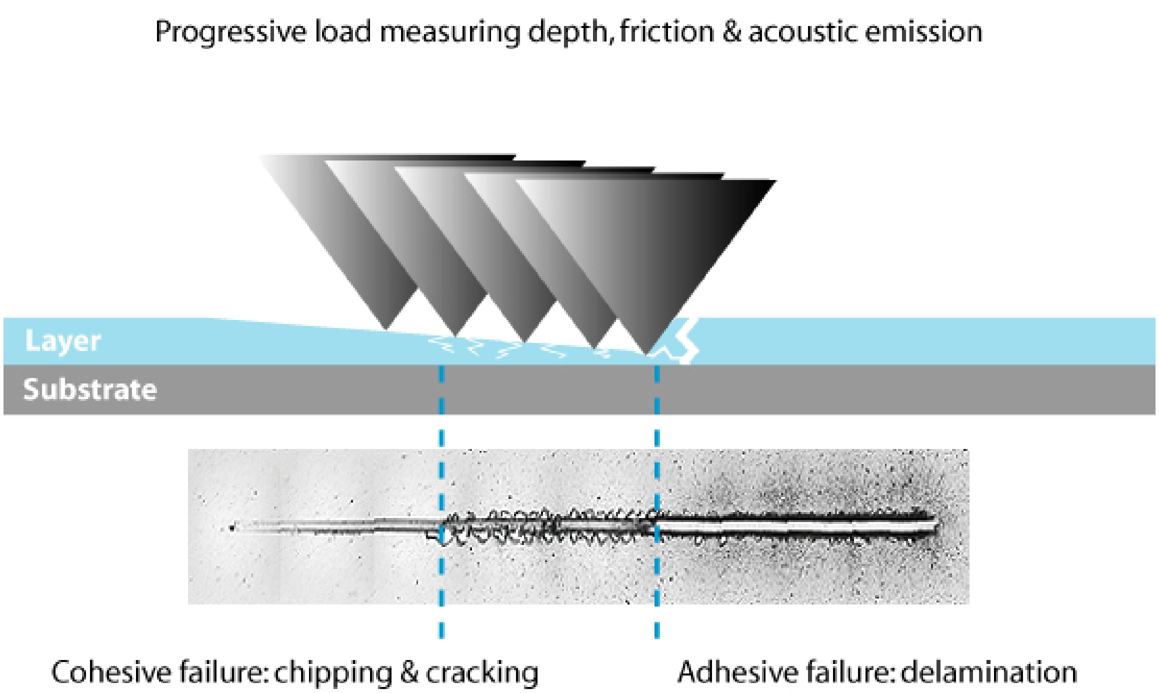
Scratch test

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 from 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 of 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.



Comments on the critical load

The scratch test gives reproducible quantitative data that can be used to compare the behavior of various coatings. The critical loads depend on the mechanical strength (adhesion, cohesion) of a coating-substrate composite but also on several other parameters: some of them are directly related to the test itself, while others are related to the coating-substrate system. The parameters that determine the critical loads are summarized in Table 2.

Test specific parameters	Sample specific parameters
Loading rate	Friction coefficient between surface and indenter
Scratching speed	Internal stresses in the material for bulk materials
Indenter tip radius	Material hardness & roughness for coating-substrate systems
Indenter material	Substrate hardness and roughness
	Coating hardness and roughness
	Coating thickness

Table 2: List of parameters that determine the critical loads.

Means for critical load determination

Microscopic observation

This is the most reliable method to detect surface damage. This technique is able to differentiate between cohesive failure within the coating and adhesive failure at the interface of the coating-substrate system.

Tangential (frictional) force recording

This enables the force fluctuations along the scratch to be studied and correlated to the failures observed under the microscope. Typically, a failure in the sample will result in a change (a step, or a change in slope) in coefficient of friction. Frictional responses to failures are very specific to the coating-substrate system in study.

Acoustic emission (AE) detection

Detection of elastic waves generated as a result of the formation and propagation of microcracks. The AE sensor is insensitive to mechanical vibration frequencies of the instrument. This method of critical load determination is mostly adequate for hard coatings that crack with more energy.

Depth Sensing

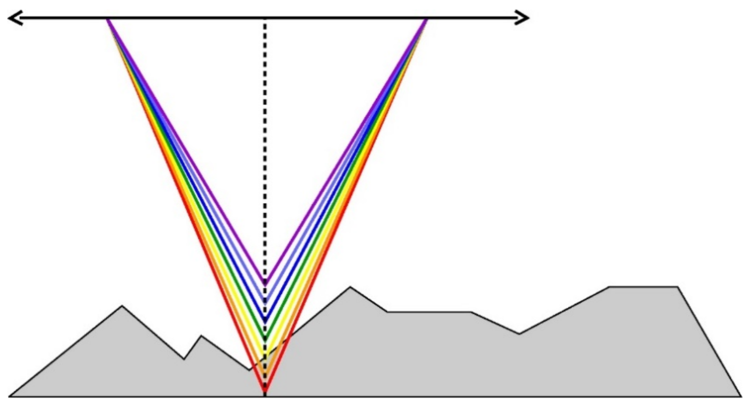
Sudden change in the depth data can indicate delimitation. Depth information pre and post scratch can also give information on plastic versus elastic deformation during the test. 3D Non-Contact imaging such as white light axial chromatism technique and AFMs can be useful to measure exact depth of scratch after the test.

Other possible measurements by Nanovea Mechanical Tester:

Hardness and Young's Modulus, Stress-Strain & Yield Stress, Fracture Toughness, Compression strength, Fatigue testing and many others.

Non-contact profilometry

The axial chromatism technique uses a white light source, where light passes through an objective lens with a high degree of chromatic aberration. The refractive index of the objective lens will vary in relation to the wavelength of the light. In effect, each separate wavelength of the incident white light will re-focus at a different distance from the lens (different height). When the measured sample is within the range of possible heights, a single monochromatic point will be focalized to form the image. Due to the confocal configuration of the system, only the focused wavelength will pass through the spatial filter with high efficiency, thus causing all other wavelengths to be out of focus. The spectral analysis is done using a diffraction grating. This technique deviates each wavelength at a different position, intercepting a line of CCD, which in turn indicates the position of the maximum intensity and allows direct correspondence to the Z height position.



Nanovea optical pens have zero influence from sample reflectivity. Variations require no sample preparation and have advanced ability to measure high surface angles. Measure any material: transparent/opaque, specular/diffusive, and polished/rough.

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[i] **http://www.metcoat.com/corrosion-resistant-coatings.htm**