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SCRATCH ADHESION TESTING
OF COMPACT DISC COATING

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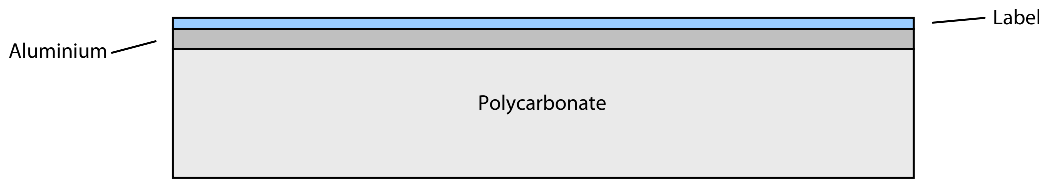
INTRODUCTION:

A compact disc (CD) is an optical disc used to store music and data by writing data as pits in a reflective layer. The CD is available on the market since 1982 and is, to this day, the preferred physical medium for music. The CD is composed of a 1.2mm disc of polycarbonate with a thin layer of aluminum. The aluminum is protected by film of lacquer. On some CDs, a label material is then deposited.



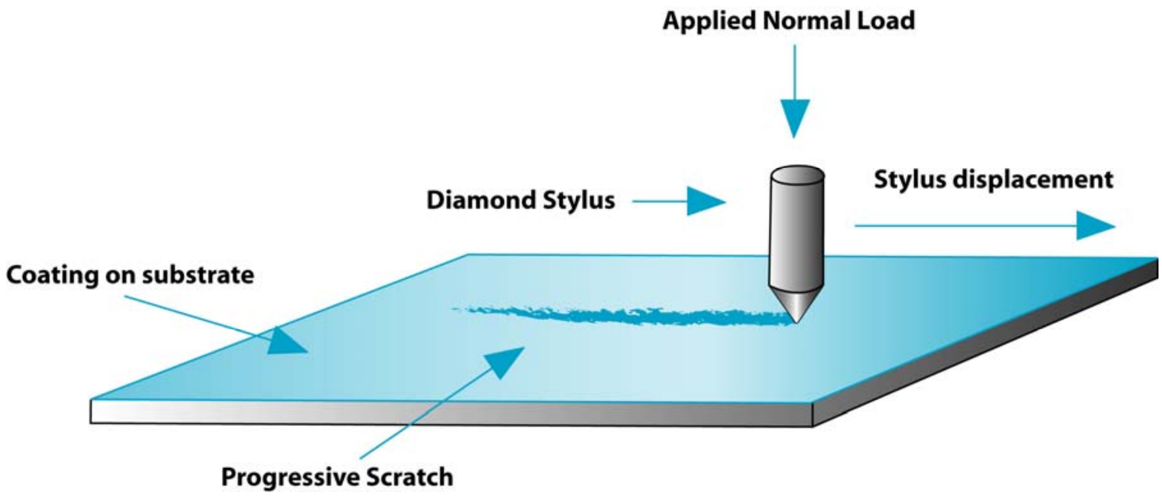
The data on the CD is written by "burning" pits in the aluminum layer on the polycarbonate side. This data is then read by measuring the change in intensity in the reflected laser beam. Scratches and defects on the polycarbonate side will have a limited influence on the ability to read the data since they are out of focus. The scratches on the label side are much more critical, since they can damage the aluminum layer directly.

In this test, instrumented scratch testing is used to observe the failure modes of the top layers of two different brands of CDs. This test will also allow us to quantitatively compare the adhesion of the aluminum layer to the polycarbonate by measuring the critical loads at which adhesion failure occurs. After performing the scratch test, the profilometer will be used to measure the full 3D topography of the scratch. This will provide the precise measurements of size, shape and area of the scratch damage.

SCRATCH TEST METHOD:

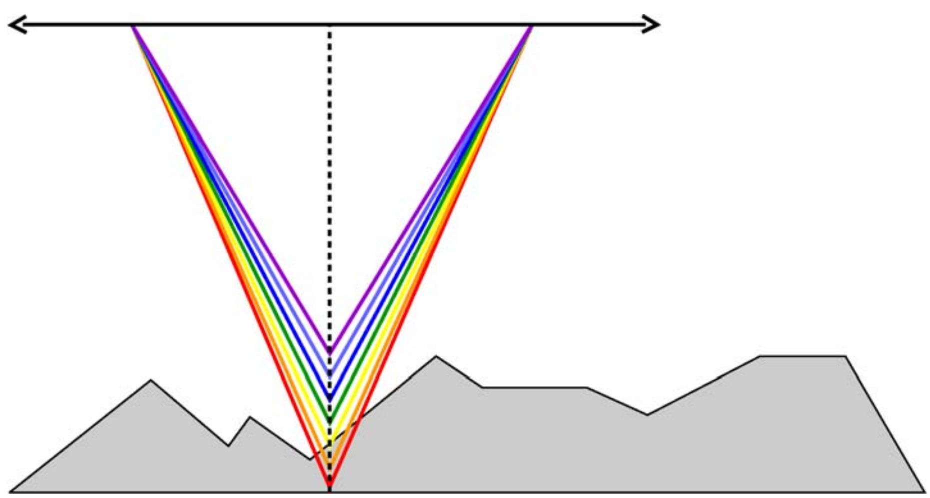
The scratch testing method is a comparative test in which critical loads at which failures appear in the samples are used to evaluate the relative cohesive or adhesive properties of a coating or bulk material. During the test, scratches are made on the sample with a sphero-conical stylus (generally Rockwell C diamond, tip radius ranging from 20 to 200μm) 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.

When performing a progressive load test, the critical load (L_c) is defined as the smallest load at which a recognizable failure occurs. The driving forces for coating damage in the scratch test are a combination of elastic-plastic indentation stresses, frictional stresses and the residual internal stresses. In the lower load regime, these stresses generally result in conformal or tensile cracking of the coating which still remains fully adherent. The onset of these phenomena defines a first critical load. In the higher load regime, one defines another critical load which corresponds to the onset of coating detachment from the substrate by spalling, buckling or chipping.



PROFILOMETRY MEASUREMENT PRINCIPLE:

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.

TEST PARAMETERS:

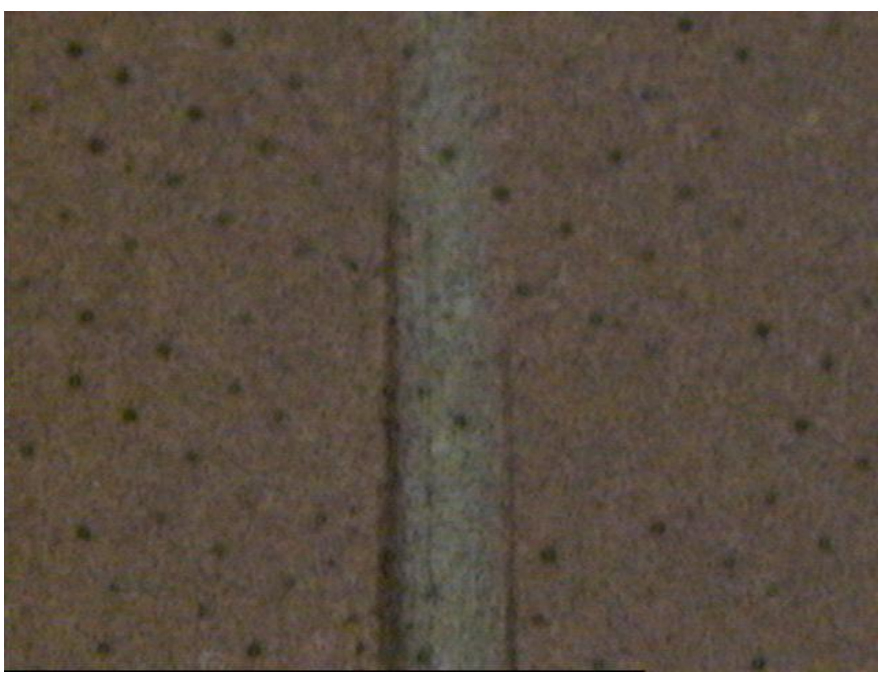
For this application, the test parameters used are the following:

Loading mode	Progressive (linear)
Initial Load	0.1 N
Final Load	25 N
Loading Rate	25 N/min
Scratch Speed	20 mm/min
Scratch Length	20 mm
Indenter Type	Sphero-Conical
Indenter Radius	200 μm

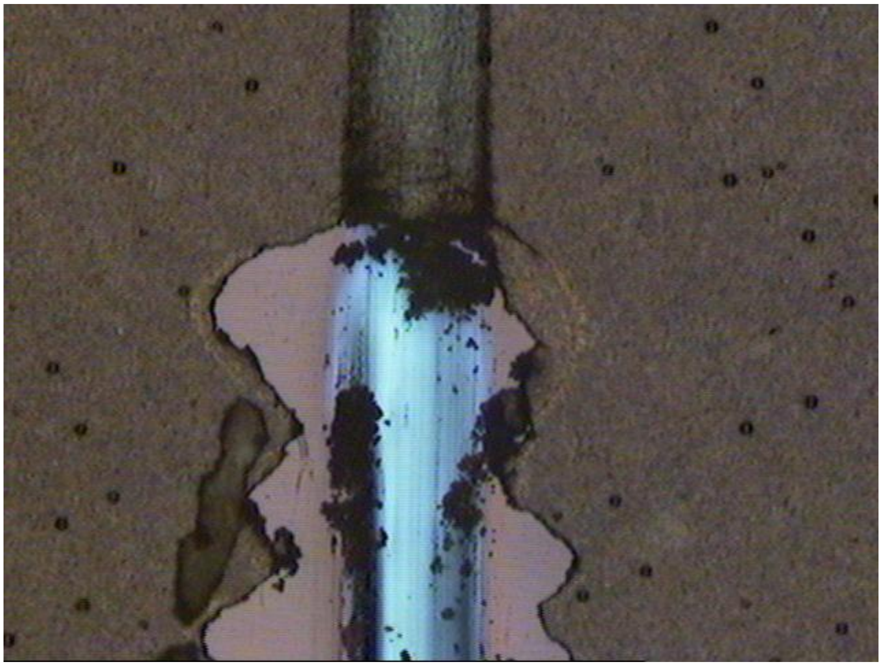
SCRATCH TEST RESULTS:

In the following section the data gathered during the test is presented. This includes micrographs of different failure modes in the scratch, the critical loads at which the failures of interest occur, and a graph of coefficient of friction over scratch length.

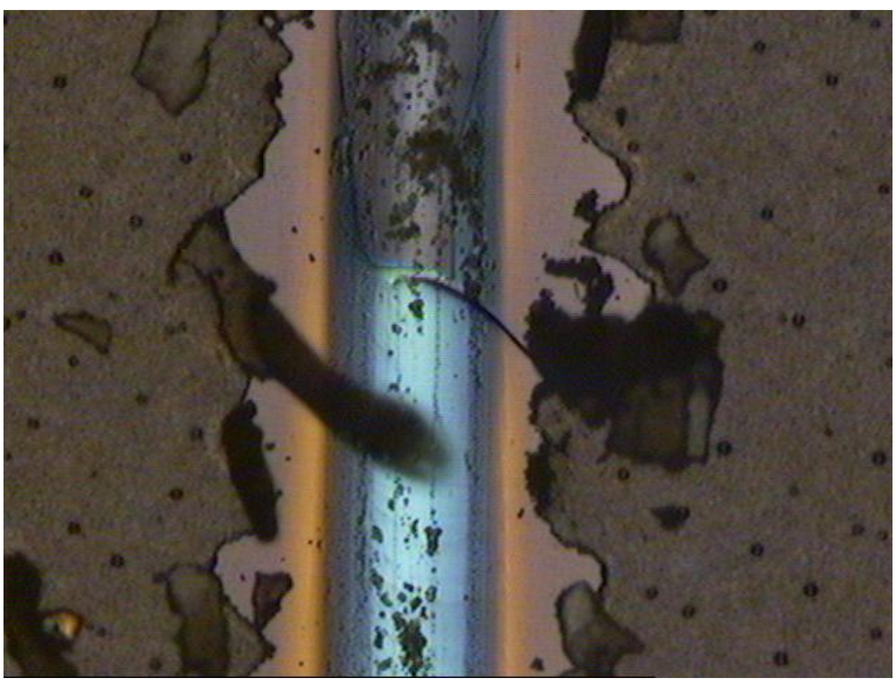
The indenter initially deforms and marks the label layer without removing it.



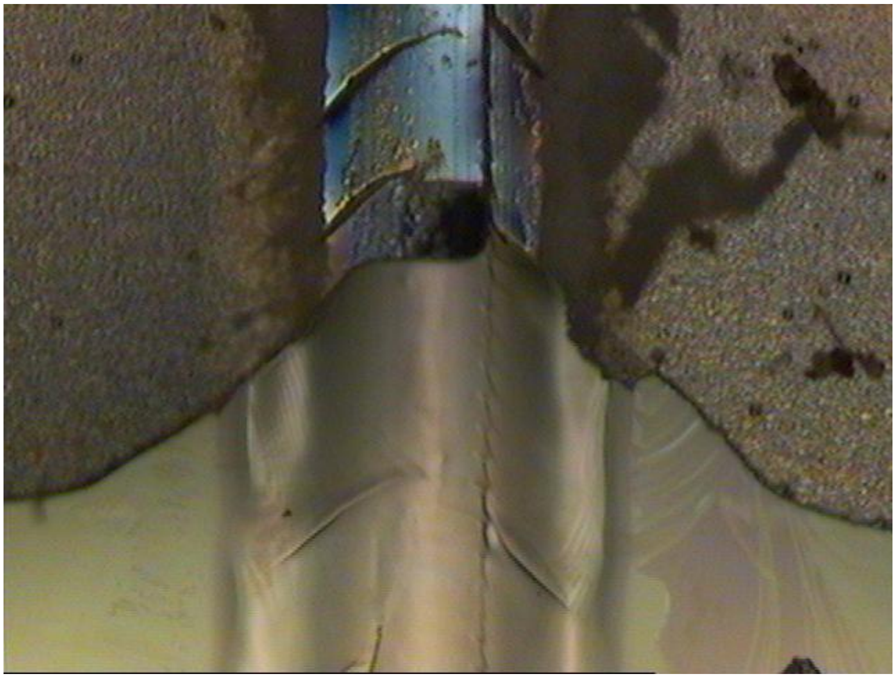
The failures of both layers are visible in this scratch. At 3.163 N, spallation of the label (top) layer is clearly visible, as shown in the following micrograph.



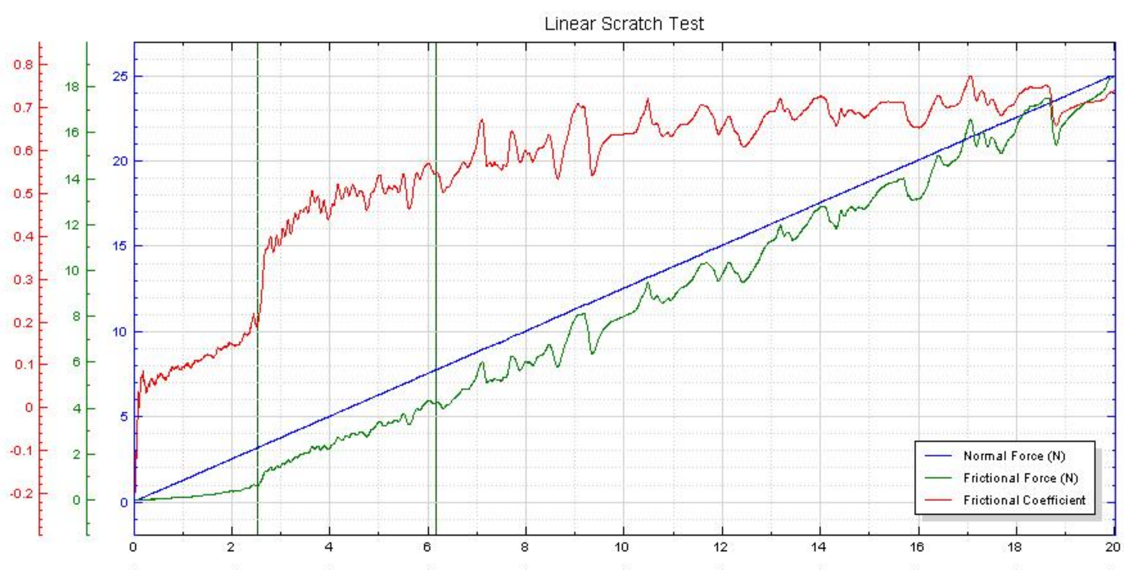
Between 3N at 6N, the label is continuously delaminating while the aluminum layer remains adherent.



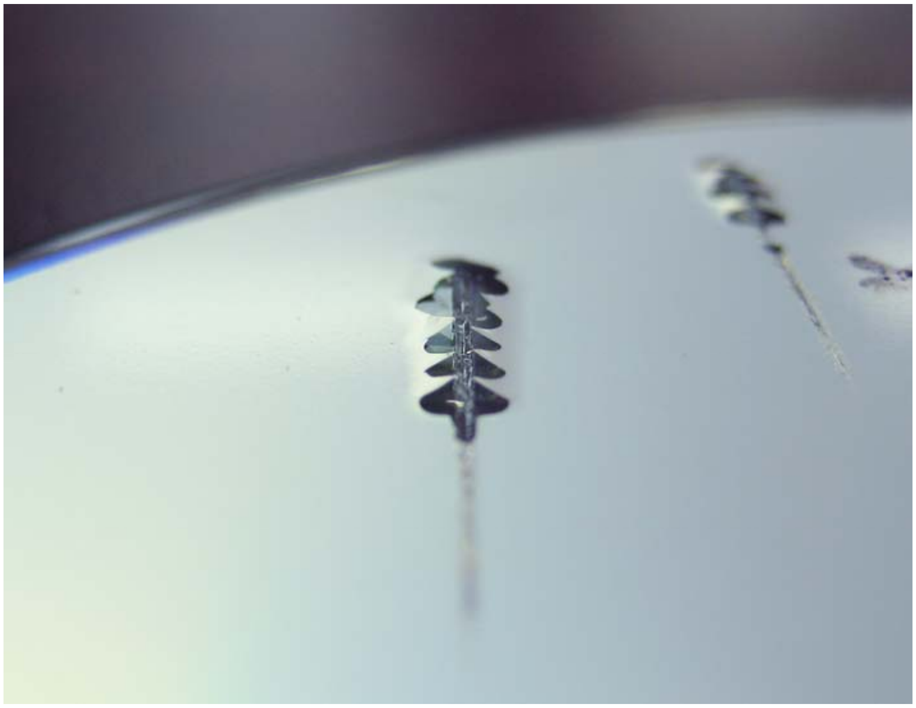
At 6.172 N, large spallation of the aluminum layer is observable.



The following graph shows the recorded normal (vertical) and frictional (lateral) forces during the test as well as the coefficient of friction, over distance in mm. The vertical lines mark where the critical loads for both delaminations were recorded. At the delamination point of the label layer, there is a jump in the coefficient of friction because of the additional work performed by the indenter to remove the layer. At the delamination point of the aluminum layer, the friction starts to oscillate noticeably, due to the uneven work performed by the indenter when chipping the aluminum layer. Most likely, every drop in friction in the last part of the graph relates to a piece of aluminum being chipped off.



The following photograph shows the macroscopic damage performed by the scratch.



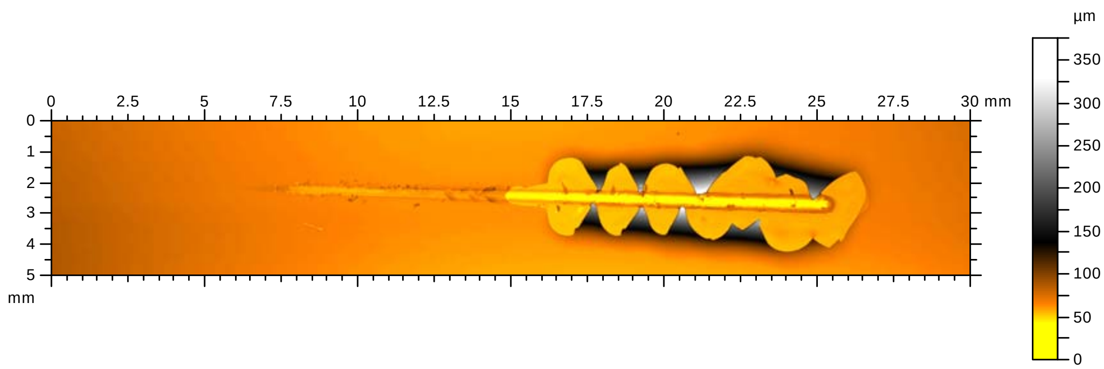
DISCUSSION OF THE SCRATCH RESULTS:

The test parameters were determined during preliminary testing. Often, to find the optimal parameters, it is good to perform a progressive scratch with a medium final load, and then try higher or lower load if the critical failure of interest is not happening, or happening too close to the initial scratching point, respectively.

With these optimal parameters, we were able to perform a scratch that showed to relevant critical failures, one relating to the adhesion of the label to the aluminum, one relating to the adhesion of the aluminum to the polycarbonate. We are then able to use the critical loads at which these failures happen to compare adhesion strength of these interfaces with those of a similar sample on which we would perform a scratch test with the same parameters.

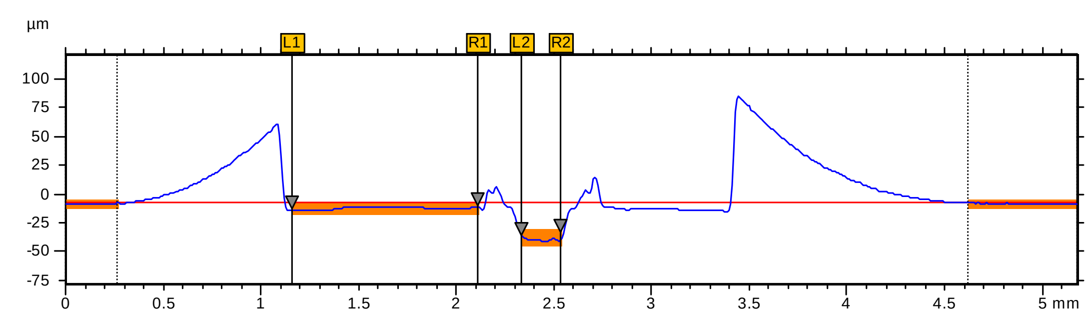
PROFILOMETRY MEASUREMENT RESULTS:

While scratch testing is a test that does not require additional measurements to provide relevant results, since the scratch is inspected in 2D by microscope, using an optical profiler can prove very useful to 3D image and precisely measure physical dimensions of the scratch damage in all three dimensions.



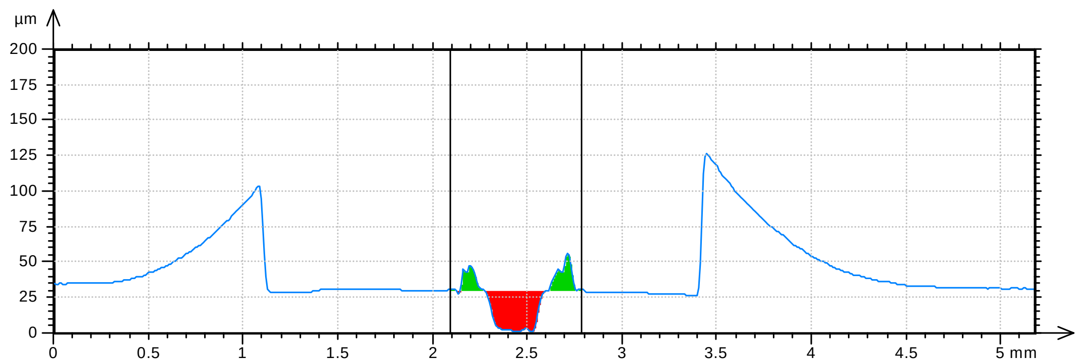
It is important to note that measurements such as these could not be preformed without non-contact profiling. Stylus profilers would push down the damaged aluminum peels or peel them off even with the use of very light loads. Also, scratch testing often leaves loose debris that stylus profilers could not measure without moving them around.

After leveling the surface, the analysis software can compare the average height of the surface with the coating and the bare polycarbonate surface (with the Al and label layers peeled off). The step height indicates a thickness of approximately 4.02um. By extracting a profile at the end of the scratch, we measure a depth of the scratch at the maximum load of 31.12um. Both step height measurements are illustrated on the following figure.



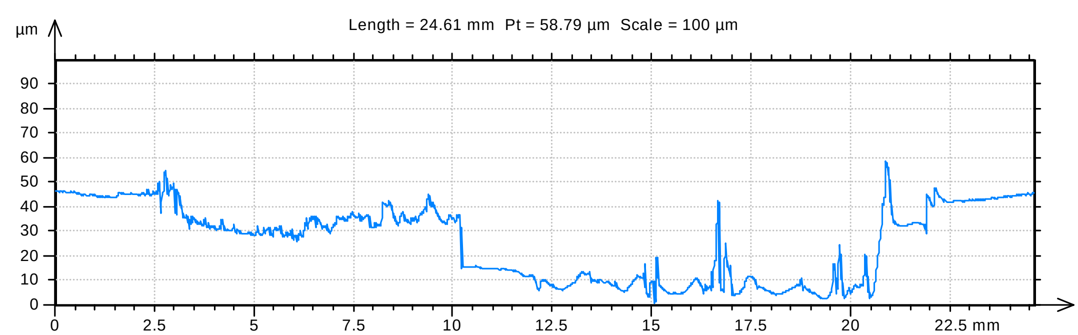
	1	2
Maximum height	5.978 µm	33.4 µm
Mean height	4.016 µm	31.12 µm

The topography data gathered also allows measuring the cross-sectional area of the track, and pile-up on the side of the scratch. As shown on the following figure, the track area is 7105µm^2 and the area of the pile-up is 3066µm^2. With the 3D data gathered, we can also measure that the volume of material removed during the scratch is 0.367mm^3.



Maximum depth :	30.27 µm	Area of the hole :	7105 µm2
Maximum height :	26.34 µm	Area outside :	3066 µm2

The following figure shows the depth profile along the bottom of the scratch track.



CONCLUSION:

In conclusion, the Nanovea Scratch Tester is able to cause adhesive failure in a controlled and closely monitored fashion in order to measure critical loads to use as a quantitative value for comparing adhesion strength in similar samples. This test also shows that it can also be possible to determine the critical loads of multiple layer interfaces in a multi-layer system. The Nanovea ST400 and PS50 profilometers can also be used to provide virtually any dimensional information about the scratch damage to the sample. Non-contact profiling is necessary in this case to measure fragile features in the material and light debris on the surface. This test demonstrated on compact disc coatings applies to most coated samples.