TestOptimizer scratch example

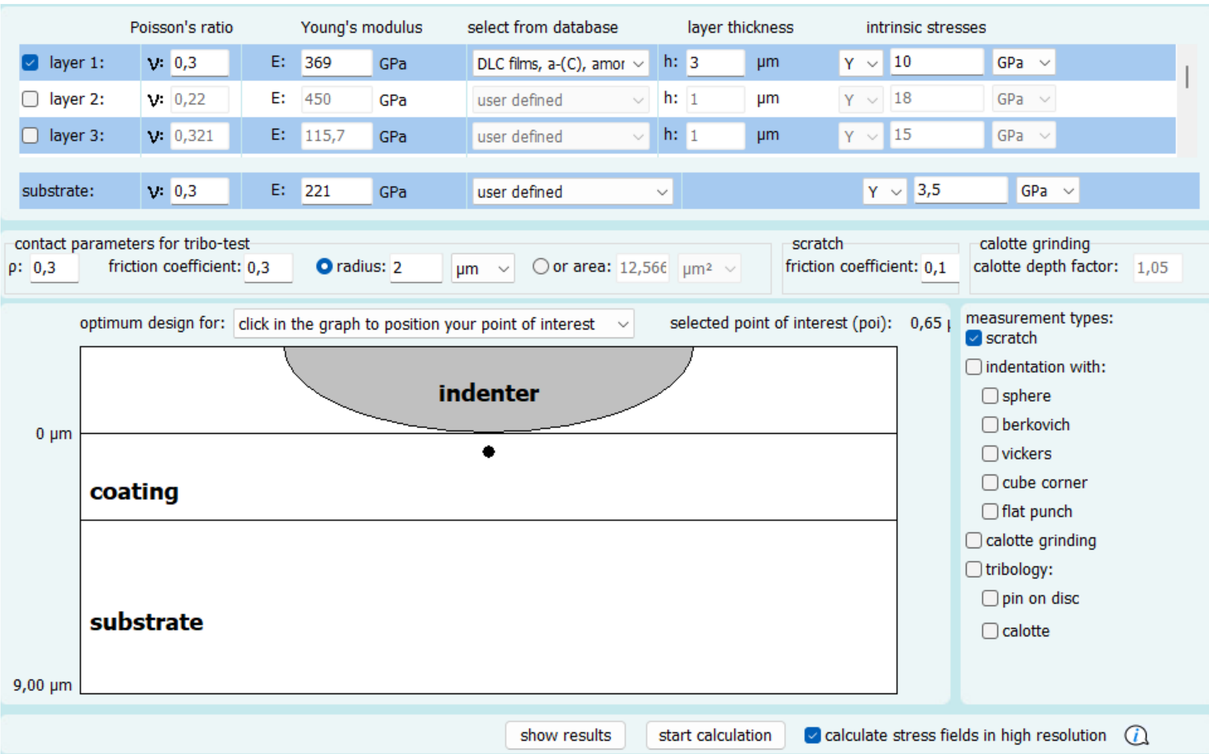
For simplicity we use a sample with one coating here, but the TestOptimizer module can be used for up to the available amount of layers in the SIO software (e.g., 10 or more layers in the FilmDoctor Studio packages).

Task

We want to test and analyze the applied coating to check if it can help increase the application performance. Therefore, we will need a test that can break/damage the coating but keeps the substrate intact.

Sample

We have a typical use case here. A substrate is coated with a 3 µm DLC coating to increase the performance. This usually means lowering the friction and/or protecting the substrate against external loads. Therefore, mostly coatings with a higher Young's modulus and yield strength values are used for such tasks. Here the Young's modulus of the coating is about 1.5 times higher (369 GPa to 221 GPa) and the yield strength about 3 times higher (10G Pa to 3.5 GPa). We assume a friction coefficient of 0.1 for this example:



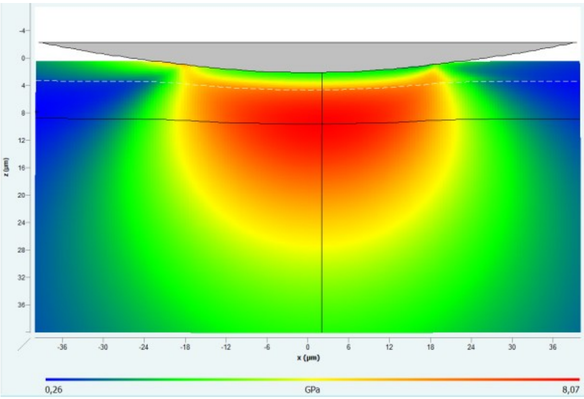
The ”wrong” or at least long way

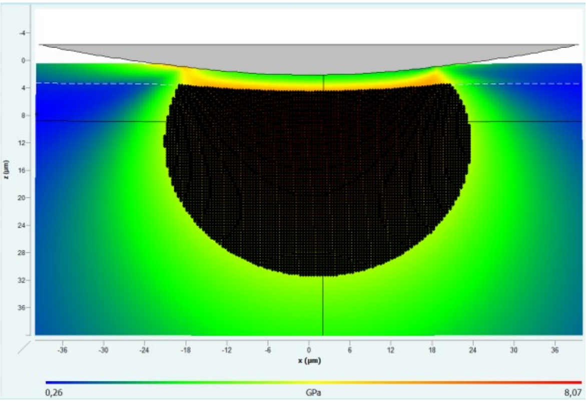
Usually the best test parameters are unknown if dealing with new materials or material combinations. So we can use personal experience, standards, or crowd knowledge. On the 19th of November 2025 the AI-generated answer from Google was this:

> *“**1-2 µm radius:** Used for nano-scratch tests to measure the mechanical properties of thin films with high precision.*
>
> ***50-200 µm radius:** Used for "severe" scratch tests that require higher loads to create more significant damage.*
>
> ***400 µm (0.4 mm) tip radius:** A common size for micro-scratch tests on coatings.”*

As you can see, there is a big gap from 2 to 50 µm between the nano and “severe” scratch tests. We want to test the coating performance not only close to the surface, so a very small tip (smaller than the coating thickness) is not what we will need. In some international standards the Rockwell tip, a sphere with a 200 µm radius, is mentioned. This is used by a lot of people as a first approach. Another unknown parameter is the load used for the scratch measurement. Let’s start with 10 N in our first simulation.

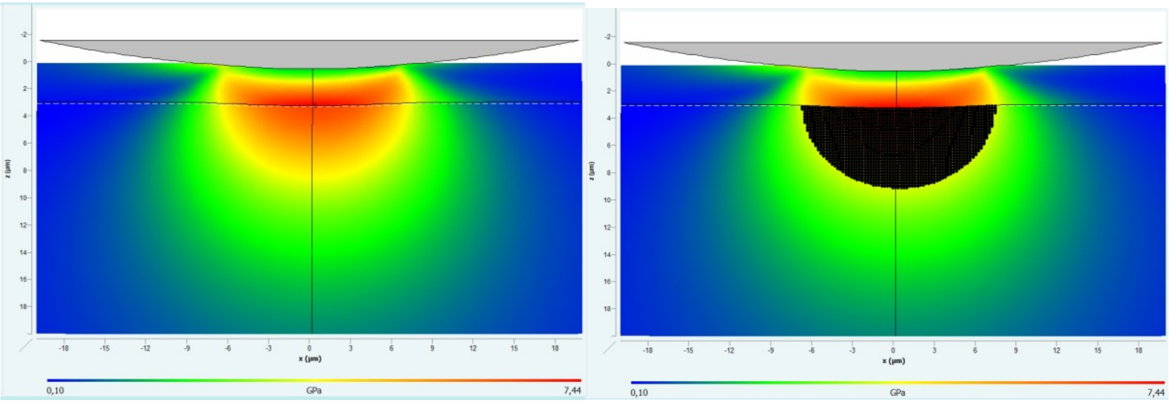
We use the FilmDoctor® software to calculate the complete stress strain-field and look at the von Mises stress field, which can indicate the start of plastic flow within a material component.





On first sight we can see that the stress field is concentrated deep in the substrate. Looking at the maximum von Mises stress value (on the lower right corner below the color bar), we can also see that this value is much higher than the yield strength of 3.5 GPa. So plastic flow will be created in the substrate, and if the coating delaminates in this test, it is triggered by the substrate damage and not by adhesion or coating problems. We can highlight this by showing the plastic zone (all the black dots).

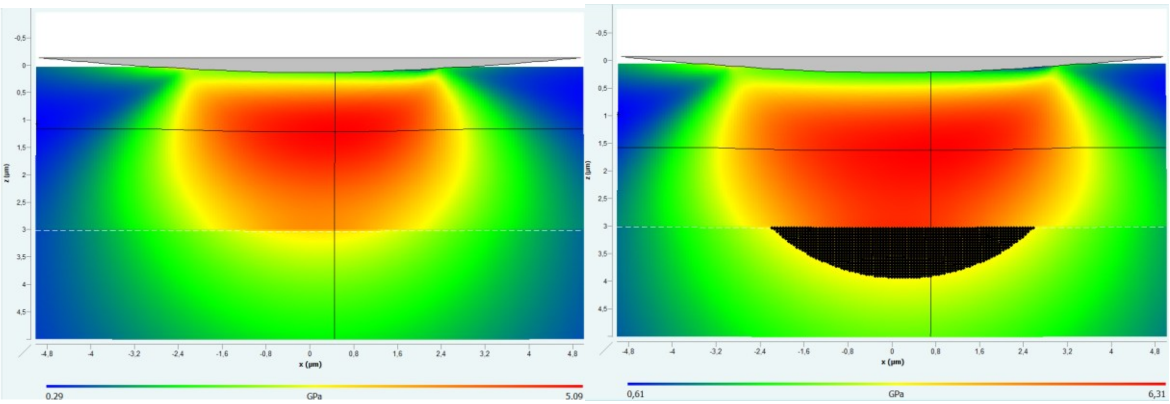
To summarize: in our first iteration, the tip size and the load were (way) too big. We halve the tip size and decrease the load to 1 N for the next simulation.



Now we can see that the stresses are concentrated around the interface between the coating and the substrate. This could be a good test setup for an adhesion test.

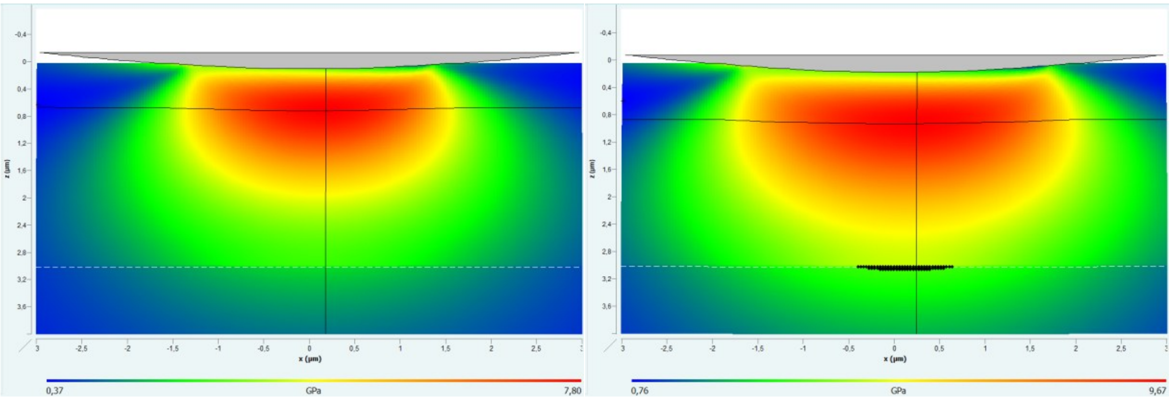
But if we show the plastic zone again (black dots), we can see that substrate is still overstressed.

That means we have to decrease the tip size and load further, because we want to produce critical stresses in the coating but avoid any plastic flow within the substrate. Let's use the same factors again and decrease the tip size to 50 µm and the load to 100 mN. Now we achieved the goal to concentrate the stress field within the coating, but the von Mises stress maximum didn't reach the yield strength of the used materials. This scratch test would not create any damage related to plastic flow in our sample.



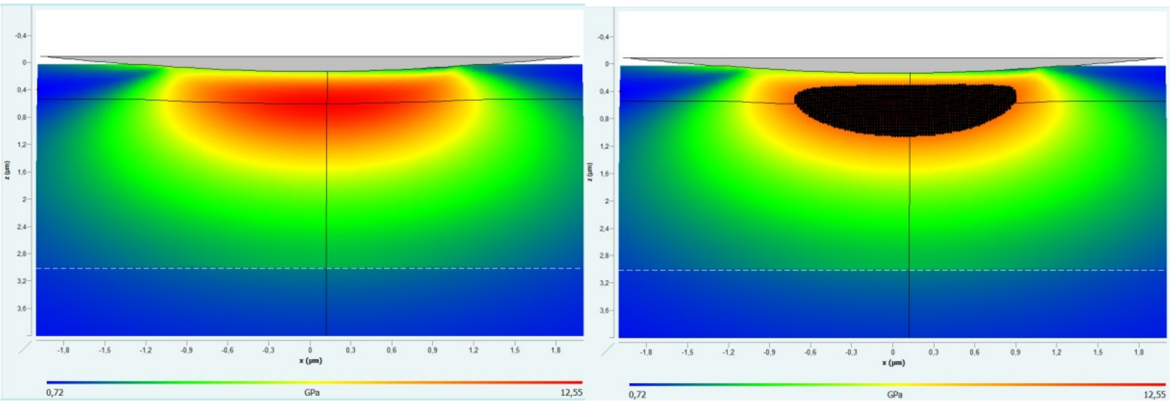
We can increase the load to reach the yield strength. The next simulation will use 200 mN. Still, the plastic flow starts in the substrate first, and we want to avoid it. This means we will need an even smaller indenter tip.

So, let’s go down to 20 µm and use a load of 50 mN. The stressed are nicely concentrated within the coating but the yield strength of 10 GPa is not reached:



We will keep the indenter and increase the load to 100 mN. Now we are very close to the needed test conditions. The maximum von Mises stress value of 9.67 GPa nearly reached the coating’s yield strength of 10 GPa, but we still created plastic flow in the substrate first.

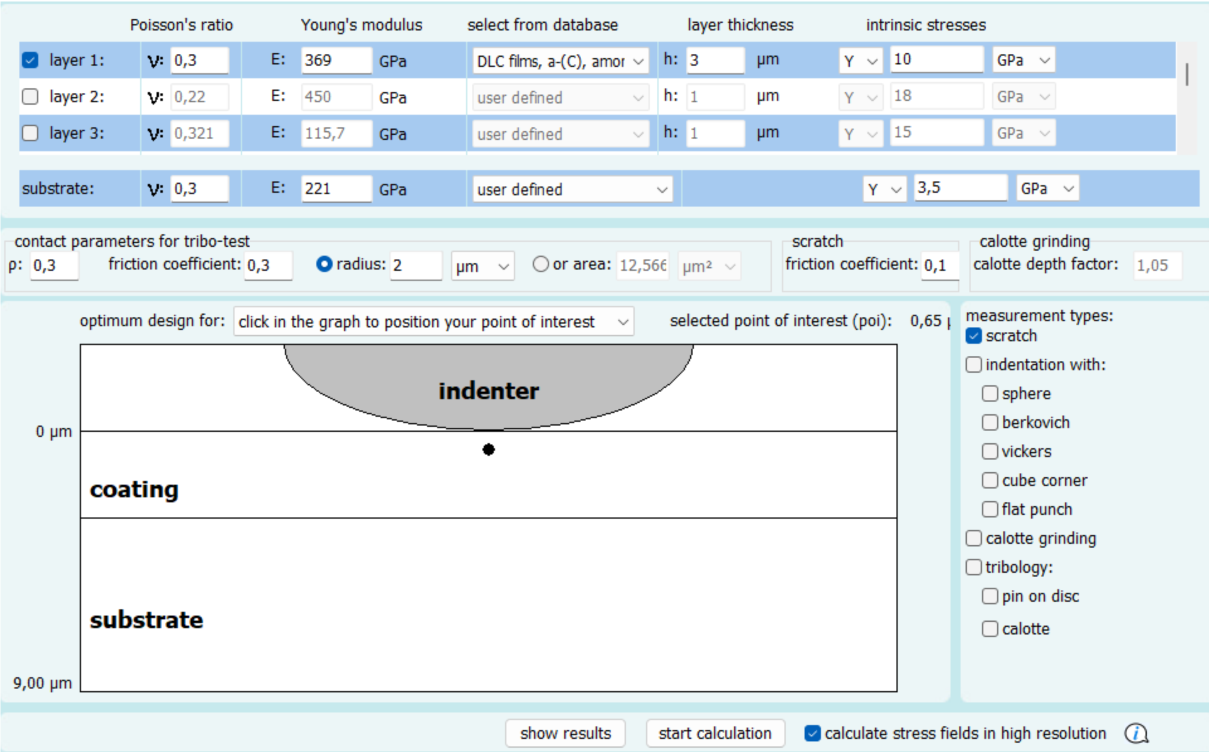
That means we have to decrease the tip size one (last) time. By using 10 µm as a radius and a load of 50 mN we can now concentrate the stress fields in the coating and exceed the yield strength:



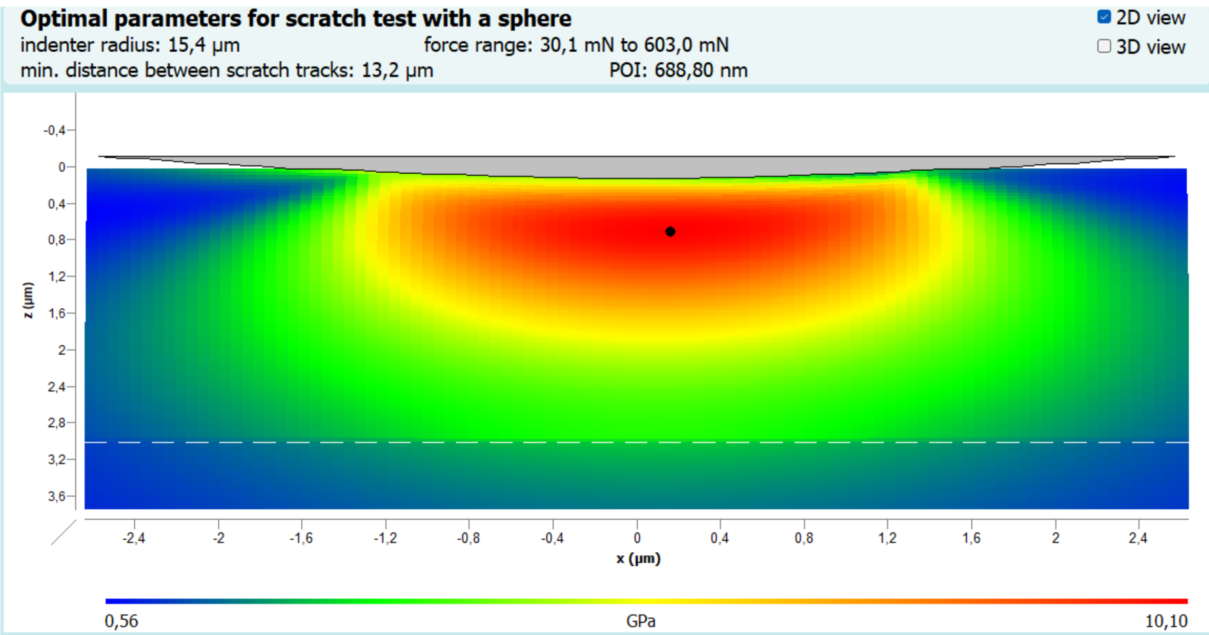
If we show the plastic zone again, we can see that now the plastic flow is produced within the coating, but the substrate is completely unharmed.

The “right” or faster way

As you could see, depending on the personal experience, it can take quite a lot of simulations or measurements to find suitable test parameters. The TestOptimizer module can give us the results in one step. We need to enter the material parameters, set the assumed friction coefficient, and define in which part of the coating the stress field should be concentrated.



The TestOptimizer then performs simulations similar to the ones we did by hand in the background until a solution that fulfills our inputs is found. The results, together with the von Mises stress distribution field, are shown afterwards. The TestOptimizer suggests a tip with a radius of 15.4 µm and a load between 30.1 mN and 603 mN. This load range is given because usually scratch tests are performed with progressive load, and the coating will not delaminate directly after the plastic flow is initiated. The stress image was calculated using a load of 60.2 mN. We now have to check which owned indenter tip comes closest to the optimal indenter shape of 15.4 µm.



Summary

With both ways we found suitable test parameters for a scratch measurement, which will create damage within the coating but keep the substrate alive. The TestOptimizer will always need one go for these results, and the number of steps needed using the “by hand” approach strongly depends on the personal experience of the customer and the quality of the guesses, especially the starting parameters.

	By Hand	TestOptimizer
Load	50 mN	30.1 to 603 mN
Tip radius	10 µm	15.4 µm
Max stress depth	582 nm	688 nm