COHESIVE AND ADHESIVE STRENGTH OF DLC ON DIFFERENT STEEL SUBSTRATES

Prepared by
Duanjie Li, PhD

6 Morgan, Ste156, Irvine CA 92618 · P: 949.461.9292 · F: 949.461.9232 · nanovea.com
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INTRODUCTION

The combination of excellent wear resistance and very low friction makes diamond-like carbon (DLC) an ideal protective coating for a variety of industrial applications, such as razor blades, metal cutting tools, bearings, motorcycle engines, and medical devices. For example, high quality tooling components, such as drill bits, dies and molds are often coated with DLC to reduce abrasive wear. The low friction and great wear resistance can significantly increase the work efficiency and extend the lifespan of the tool. Its excellent tribological properties and bio-compatibility make it an ideal material for medical application.

IMPORTANCE OF MACRO SCRATCH TESTING ON DLC COATINGS

The DLC coated tools are often used under very high load and concentrated stresses, e.g. drill bits and bearings. Under such extreme conditions, sufficient cohesive and adhesive strength of the coating/substrate system becomes vital. In order to select the best metal substrate for the target application and to establish a consistent coating process for DLC, it is critical to develop a reliable technique to quantitatively assess cohesive and adhesive strength of different DLC coating systems.

MEASUREMENT OBJECTIVE

In this study, we showcase that the macro scratch mode of Nanovea Mechanical Tester provides an ideal tool to evaluate the cohesive/adhesive strength of the protective DLC coatings under a high pressure in a controlled and quantitative manner. Instrumented scratch testing is carried out to assess the failure modes of two DLC coatings on different steel substrates.

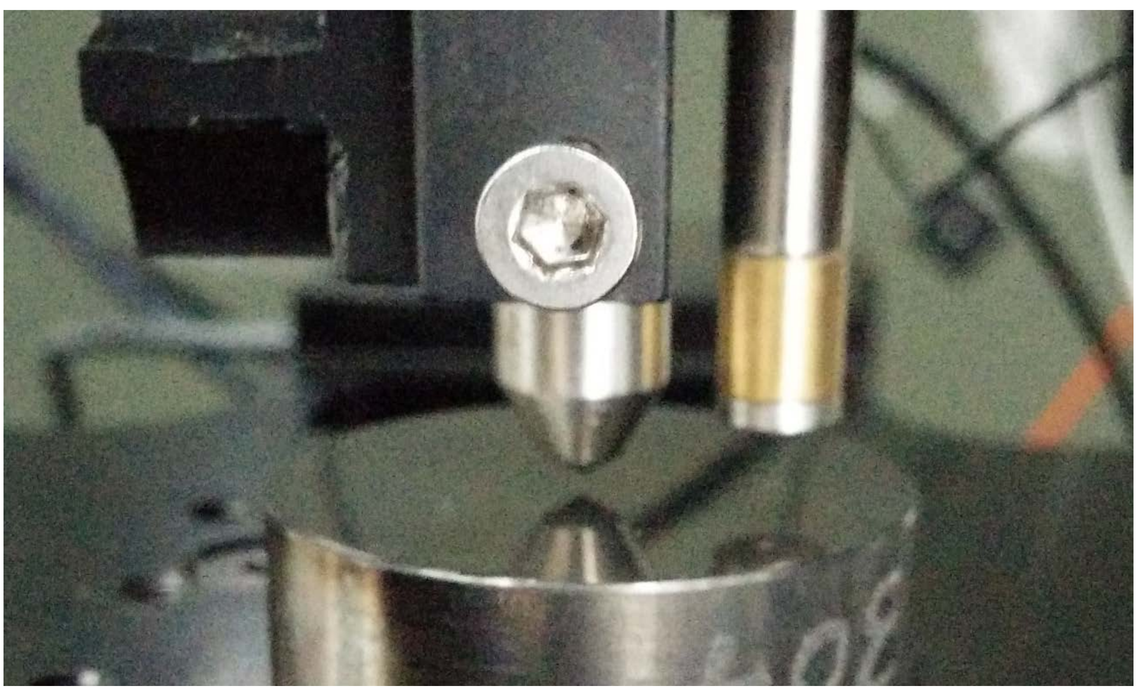


Fig. 1: Scratch tip on the DLC sample.

TEST PARAMETERS

The Nanovea Mechanical Tester was used to perform the scratch tests on two DLC coatings on different steel substrates using the same test parameters as summarized in Table 1.

Loading mode	Progressive linear
Initial Load	0.1 N
Final Load	100 N
Loading Rate	100 N/min
Scratch Speed	3 mm/min
Scratch Length	3 mm
Indenter Type	Sphero-Conical
Indenter Radius	200 µm

Table 1: Test parameters of the scratch tests on the DLC samples.

RESULTS AND DISCUSSION

The following graph shows the recorded evolution of depth and coefficient of friction (COF) as a function of applied normal load during the test. It can be observed that DLC1, which has a steel substrate of higher hardness, exhibits a penetration depth of ~14 µm, compared to ~36 µm for DLC2. Meanwhile, the COF progressively increases as the stylus penetrate into the sample. The DLC1 and DLC2 exhibit a low COF of ~0.1 at the beginning of the scratch test, due to the superior self-lubrication property of DLC. The steel substrate starts to be exposed as the DLC coating fails under the high pressure applied by the stylus, leading to gradually increased COF as the scratch test continues.

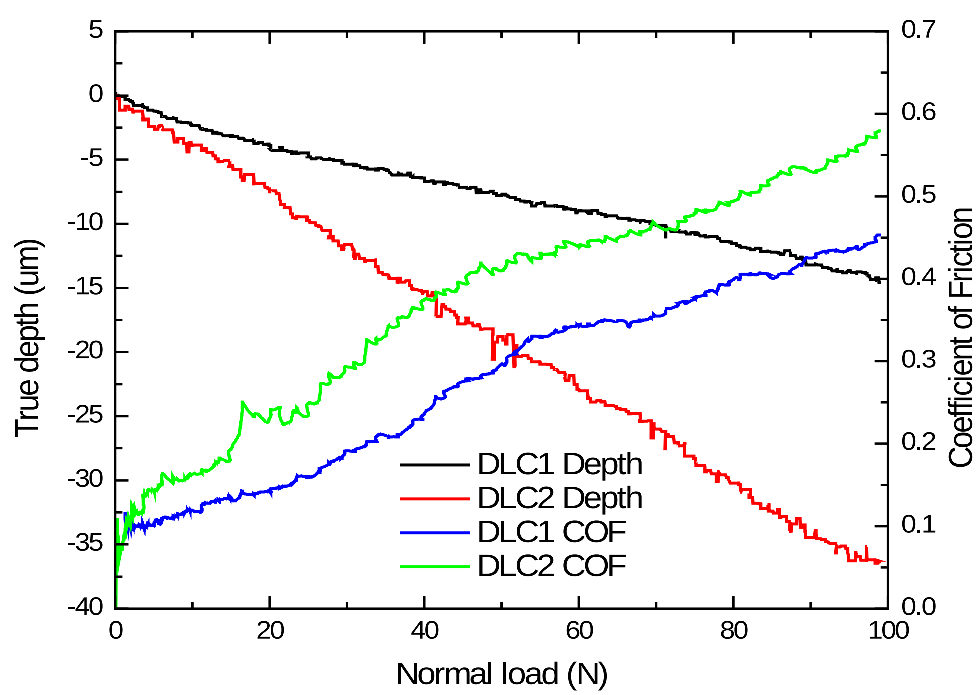
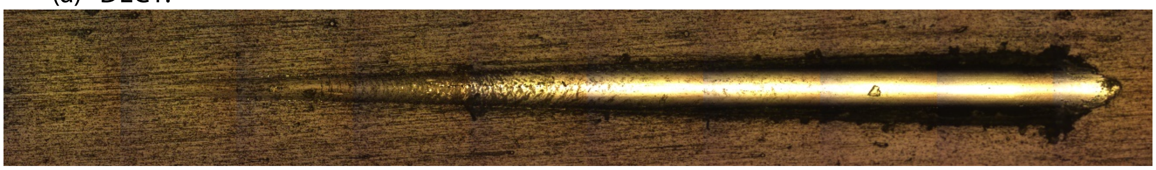


Fig. 2: Evolution of depth and COF of the DLC samples at different loads.

The full micro scratch tracks on the DLC samples are shown in Fig. 3. The failure behaviors at different critical loads are displayed in Fig. 4, where critical load L_{c1} is defined as the load at which the first sign of cohesive crack occurs in the scratch track, L_{c2} is the load after which adhesive failures take place and the steel substrate starts to be exposed, and L_{c3} is the load at which the coating is completely removed from the substrate. It can be observed that DLC1 shows a smaller scratch track compared to DLC2. DLC1 exhibits lower critical loads at different stages of the scratch tests compared to DLC2. It demonstrates the importance of proper substrate support on the cohesive and adhesive strength of the coating/substrate system. A substrate with a higher hardness is critical to resist deformation under a high external load and concentration stress.

(a) DLC1:



(b) DLC2:

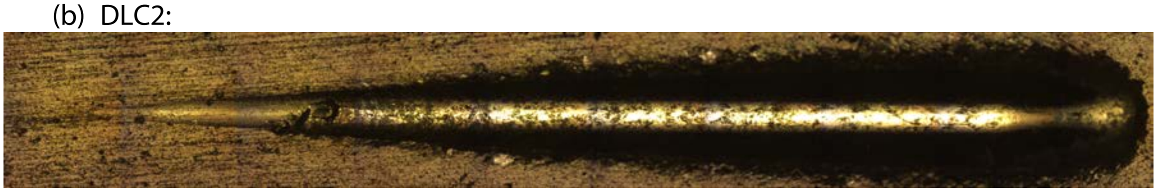
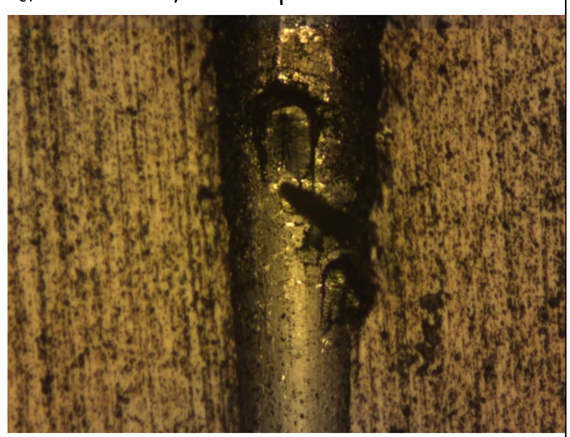


Fig. 3: Full scratch track of the DLC coatings on different steel substrates.

(a) DLC1:	(b) DLC2:
L_{c1}: N = 24.2 N, D = 4.5 μm 	L_{c1}: N = 21.7 N, D = 8.5 μm 

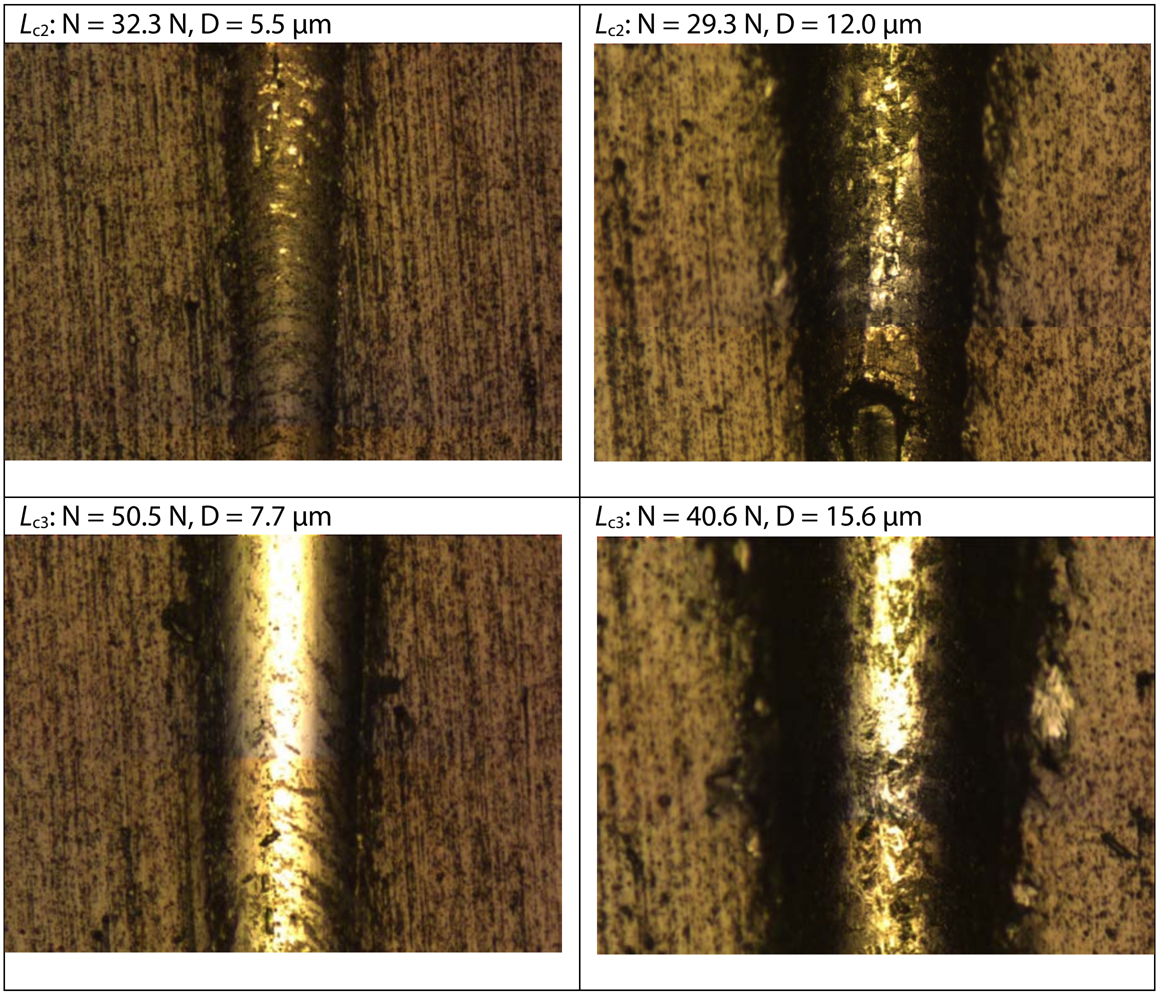


Fig. 4: DLC failures under different critical loads, L_c.

CONCLUSION

In this study, we showcased that Nanovea Mechanical Tester performs reliable and accurate macro scratch tests on the DLC coated steel sample in a controlled and closely monitored manner. The scratch measurement allows users to identify the critical load at which typical cohesive and adhesive coating failure occurs. It provides a superior tool to quantitatively evaluate and compare the intrinsic quality of the coating and the interfacial integrity of the coating/substrate system for the DLC coated metal materials for high load applications. A substrate with a higher hardness can resist large deformation under a high external load and concentration stress, which is vital for the cohesive and adhesive strength of the coating/substrate system.

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.

In addition, optional 3D non-contact profiler and AFM Module are available for high resolution 3D imaging of indentation, scratch and wear track in addition to other surface measurements such as roughness.

APPENDIX: SCRATCH TEST PRINCIPLE

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.