

ASTM D7187 TEMPERATURE EFFECT ON SCRATCH/MAR BEHAVIOR OF AUTOMOTIVE PAINT COATINGS BY NANOSCRATCHING



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TEST PARAMETERS

The Nanovea Mechanical Tester was used to perform the nanoscratch tests on the car paint coating sample using the same test parameters at different temperatures as summarized in Table 1. The sample tested at 25 °C is at the room temperature. The nanoscratch tests at 50 and 80 °C were performed in the nano oven enclosing both the sample and the indenter, providing a uniform temperature during the nanoscratch test to minimize the thermal drift and guarantee measurement accuracy. Three tests were performed at each temperature to ensure the repeatability of the test results.

Loading mode	Progressive linear
Initial Load	0.2 mN
Final Load	300 mN
Loading Rate	200 mN/min
Scratch Length	2 mm
Indenter Type	Sphero-Conical Diamond
Indenter Radius	20 µm
Temperature	25, 50 and 80 °C

Table 1: Test parameters of the nanoscratch on the car paint samples.

RESULTS AND DISCUSSION

Prescan of the coating surface at 0.1 mN was performed first to measure the topography of the undamaged coating. Postscan of the surface measured the residual topography of the scratch track. Fig. 2 shows the recorded evolution of the true depth and residual depth during the scratch tests. Here, the true depth, also called penetration depth, equals the difference between the depth of the indenter during the scratch test and that during the prescan, while the residual depth, also known as permanent plastic deformation, equals the difference between the depth of the indenter during the post and the pre scans. The full nanoscratch tracks on the car paint coating are shown in Fig. 3. The plastic resistance, PR , and the fracture resistance, FR , are compared in Fig. 4. Here, the PR value is calculated at a normal load of 100 mN, where a high applied load causes a permanent plastic deformation before fracture occurs.

$$PR = F_N / RD$$

where:

PR = plastic resistance,

F_N = the normal force in mN, and

RD = residual depth in µm

The FR value is determined by the load at which the first fracture occurs.

It is interesting to observe that the car paint sample exhibits significantly different scratch/mar behavior at elevated temperatures such as 50 and 80 °C. The coating shows increased penetration depth during the scratch tests at higher temperatures, 21.4 and 27.6 µm,

respectively, for the tests at 50 and 80 °C under a normal load of 100 mN, compared to 11.1 µm for the tests at 25 °C. However, the residual topography of the scratch tracks measured during the postscan shows that the residual depths of the scratch tracks at the normal load of 100 mN are 2.61, 1.09 and 0.36 µm, respectively, for the tests performed at 25, 50 and 80 °C.

This is also confirmed in Fig. 3: At lower normal loads below 100 mN, the car paint scratched at the room temperatures of 25 °C exhibits clear signs of permanence plastic deformation. On the contrary, even though the car paint coating becomes soft at elevated temperatures, namely 50 and 80 °C, leading to higher penetration subjected to the external force. It fully recovers after the scratch tests, leaving almost no trace of scratches upon removal of the load.

As the normal load increases during the scratch tests, the paint coating starts to show cohesive failures, i.e. cracks on the surface. The critical load at which the first fracture occurs is comparable – The *FR* value is ~125 mN for the scratch tests performed at different temperatures. As shown in Fig. 4, the car paint sample exhibits a consistent crack resistance, but significantly increased plastic resistance as the temperature rises from 25 to 80 °C. The superior mar resistance of the car paint at higher temperatures is related to the combination effects of the visco-elastic and thermal recovery.

When the concentrated pressure of the diamond tip further increases to a high level, the car paint shows different *adhesive* failure mechanisms. The paint within the scratch track breaks and the substrate is exposed at 222 mN for the tests at 25 °C. In comparison, the paint shows larger cracks and even a complete delamination starting at 190 mN for the nanoscratch test at 80 °C. Such an interesting discovery indicates that the adhesion of the car paint to the substrate plays a critical role to its service performance. Even if the car paint exhibits a better plastic resistance and good fracture resistance at higher temperatures, further interface engineering is needed to improve the coating/substrate adhesion.

The mechanical properties of the car paint can change from rubber-like materials to brittle solids when it is exposed to different weather and temperatures. The nanoscratch testing module of the Nanovea mechanical tester allows accurate evaluation of the scratch/mar behavior of the car paint at different temperatures, making it an ideal tool to quantitatively assess and closely simulate the performance of the car paint in various environment.

INTRODUCTION

The resistance of the paint to scratch and mar plays a vital role in its end use. Automotive paint susceptible to scratches makes it difficult and costly to maintain and repair. Different coating architectures of the primer, basecoat, and clearcoat have been developed to achieve the best scratch/mar resistance. Nanoscratch testing has been developed as a standard test method to measure the mechanistic aspects of scratch/mar behavior of paint coatings as described in ASTM D7187¹. Different elementary deformation mechanisms, namely elastic deformation, plastic deformation and fracture, occur at different loads during the scratch test. It provides a quantitative assessment of the plastic resistance and fracture resistance of the paint coatings.

IMPORTANCE OF NANOSCRATCH TESTING AT DIFFERENT TEMPERATURES

The mechanical properties of polymers vary from near liquid through rubber materials to brittle solids upon exposure to different temperatures. For example, the car paint surface in direct sunlight without any shade can reach as high as 80 °C. Simulating the scratch/mar behavior of the automotive paint at the service temperatures provides the most accurate evaluation of the paint performance. Moreover, the adhesion at the coating/substrate interface can also be influenced by the elevated temperatures. Nanoscratching at target application temperatures is in need to determine the cohesive and adhesive strength of the paint coatings in the service environment.

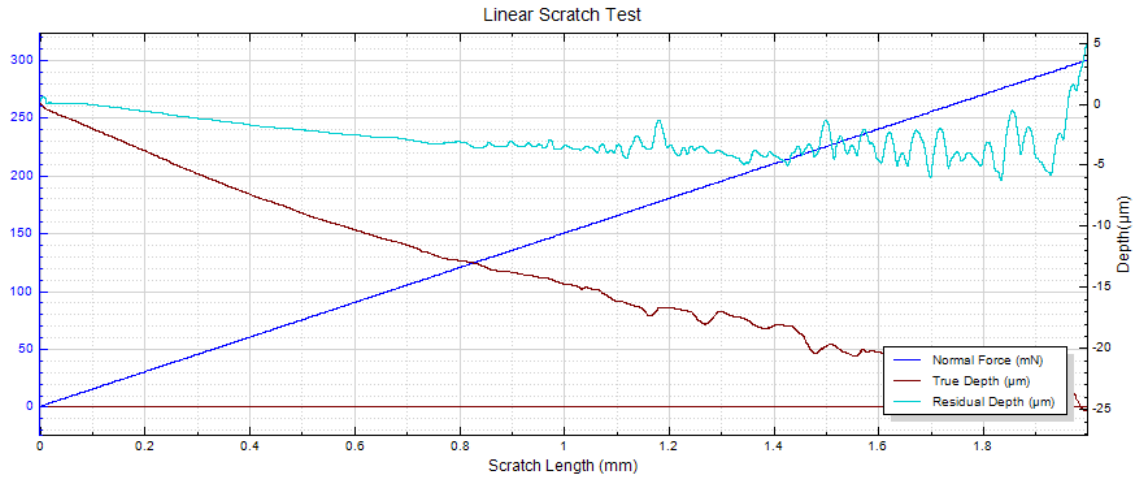
MEASUREMENT OBJECTIVE

In this study, we showcase that the nanoscratch mode of Nanovea Mechanical Tester provides an ideal tool to assess the scratch/mar behavior of the automotive paint coatings at different temperatures in a controlled and repeatable manner. The automotive paint exhibits vastly different plastic resistance and adhesive strength at elevated temperatures.

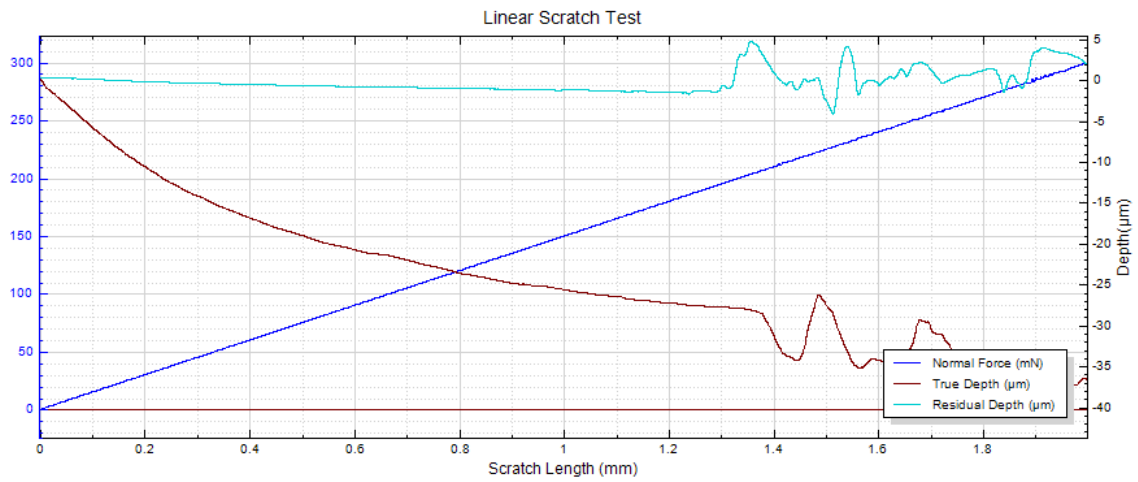


Fig. 1: Scratch tip over the heating unit.

(a) 25 °C:



(b) 50 °C:



(c) 80 °C:

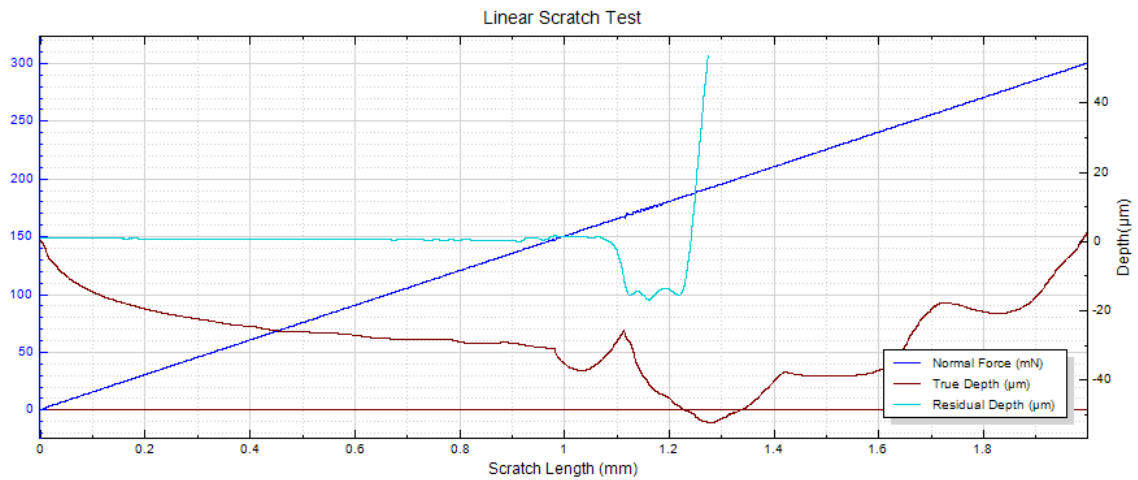
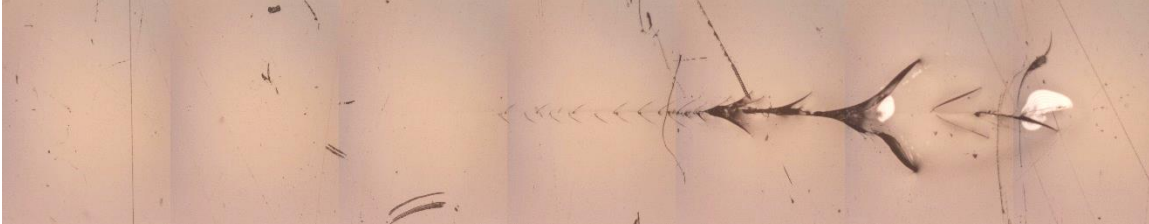


Fig. 2: Evolution of the true depth and residual depth in the scratch tests.

(a) 25 C°:



(b) 50 C°:



(c) 80 C°:

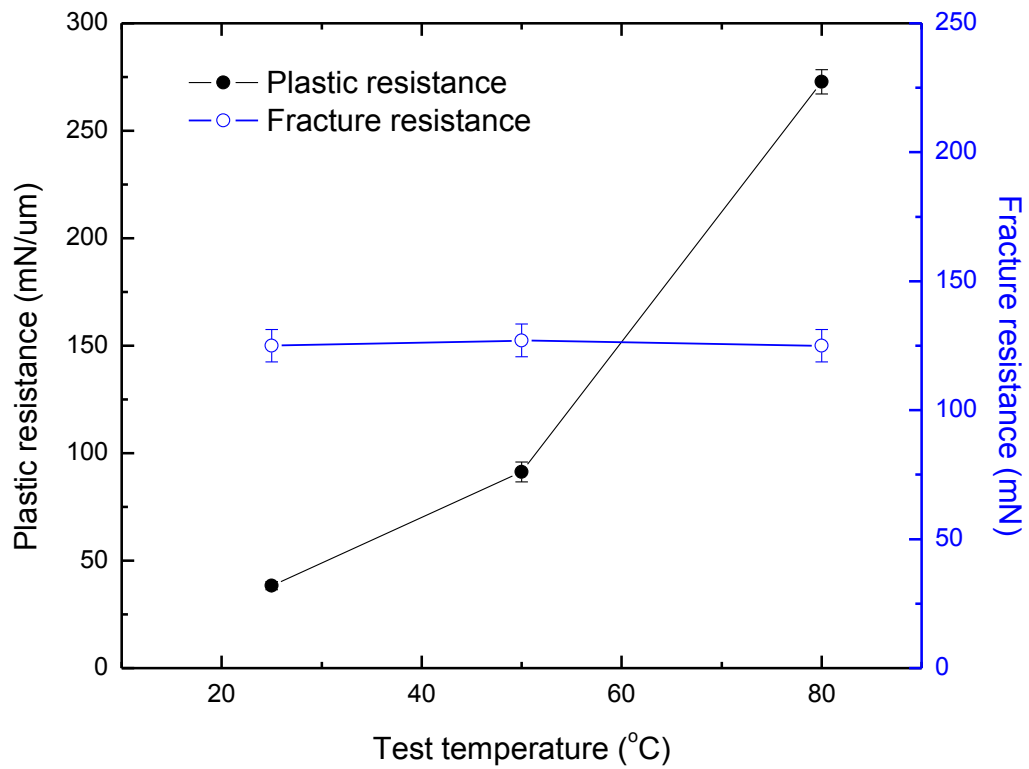


Fig. 3: Plastic and fracture resistance of the car paint coating at different temperatures.

CONCLUSION

In this study, we showcased that Nanovea Mechanical Tester performs nanoscratch tests on the car paint coating at different temperatures following the ASTM D7187 standard. The nanoscratch measurement allows users to simulate the scratch/mar behavior of the car paints exposed to different temperatures and to identify the critical load at which typical cohesive and adhesive coating failure occurs. The car paint sample in this study exhibits higher plastic resistance at elevated temperatures of 50 and 80 °C. However, the interfacial adhesion of the coating/substrate system is weakened at a high temperature of 80 °C, leading to a complete delamination of the coating under a high external stress.

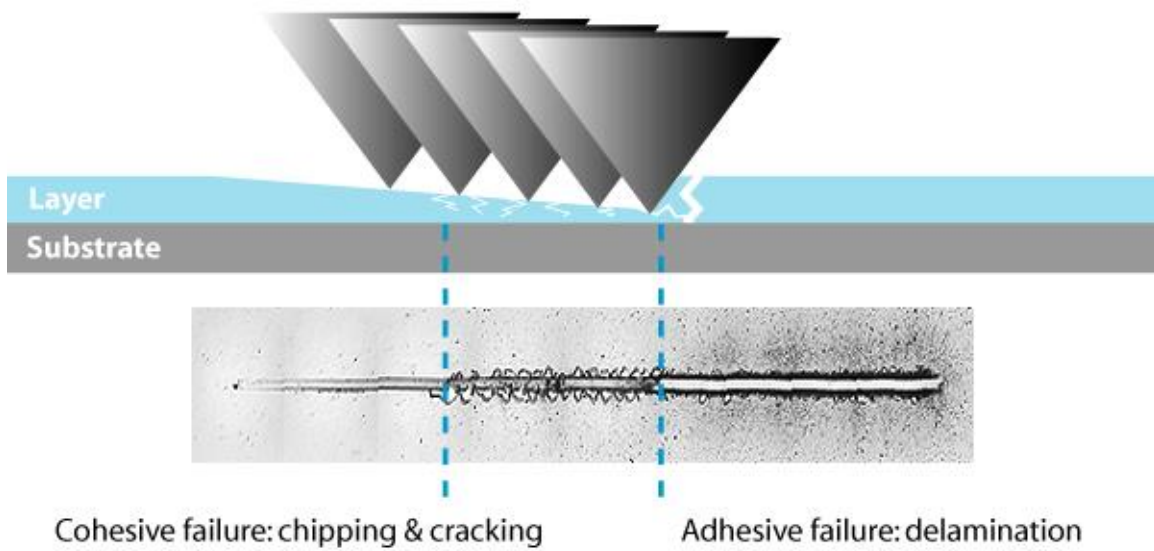
The Nano, Micro or Macro modules of the Nanovea Mechanical Tester all include ISO and ASTM compliant indentation, scratch and wear tester modes, providing the widest and most user friendly range of testing available in a single system. Nanovea's unmatched range is an ideal solution for determining the 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.

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.

Progressive load measuring depth, friction & acoustic emission



¹ <https://www.astm.org/Standards/D7187.htm>