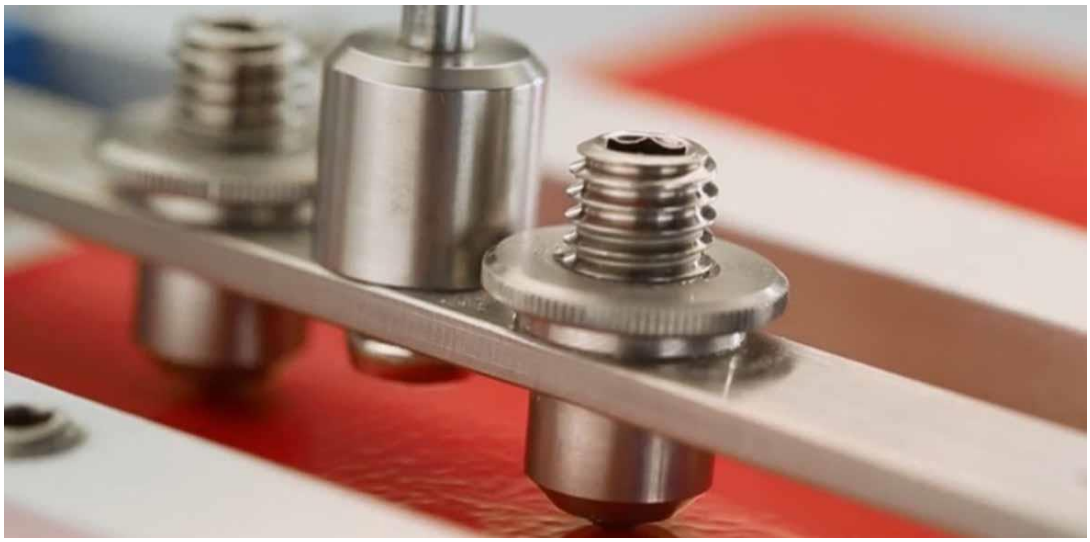
Pendulum Hardness Test

Abstract

The hardness and flexibility of a coating are opposing functionalities that need to be optimized to achieve the right balance for a specific application. A coating should have a high hardness on the one hand and be elastic at the same time. The pendulum test is used to evaluate elasticity by measuring the damping time of an oscillating pendulum. Measurement principle, test method including sample preparation and expected measurement precision are explained with typical examples from the practice.



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1 Definition of Hardness and Flexibility

Hardness is defined by the DIN EN ISO 4618 [1]. It is the resistance of a coating to a mechanical force such as pressure or scratching. It can be caused by car wash brushes, scratches from shrubs or tree branches, fingernails, animals like a cat sitting on the hood of a car or by violation with a house door key or unconsciously by sharp jewelry. Flexibility as defined in ISO 1520 [2] is the resistance of coatings, paints, varnishes, and related products to cracking and / or detachment from the substrate or deformation. Flexibility is a dynamic resistance of the coating. It can be evaluated with fast or slow deformation.

2 Pendulum Damping - A Measure for Flexibility

The pendulum test is often incorrectly referred to as a hardness test although it assesses the elastic and visco-elastic behavior of a coating. In this test, the oscillation amplitude of a pendulum is evaluated. The pendulum rests on the coating surface with two balls and is set into oscillation. The faster the amplitude decreases, the softer the coating. The damping of the pendulum movement is based on the delay of the elastic recovery of the coating after it has been deformed by the contact balls.
This method is suitable for objective evaluation of both single-layer and multilayer systems. It can be used in the development of new coatings as well as in quality control for batch testing.

3 Measurement Principle of Pendulum Hardness Test

A pendulum is placed on the surface of a coating and set in oscillation according to a specified angle of deflection. The instrument measures the time period or number of oscillations in which the oscillation amplitude drops to a value defined according to the standard. Two types of pendulums are standardized in ISO and ASTM, which differ in shape, mass, oscillation time and other parameters [2,3]. The shorter the oscillation time, the lower the hardness of the paint film. Depending on the specification, the number of oscillations or the damping time in seconds is to be recorded in the test report.

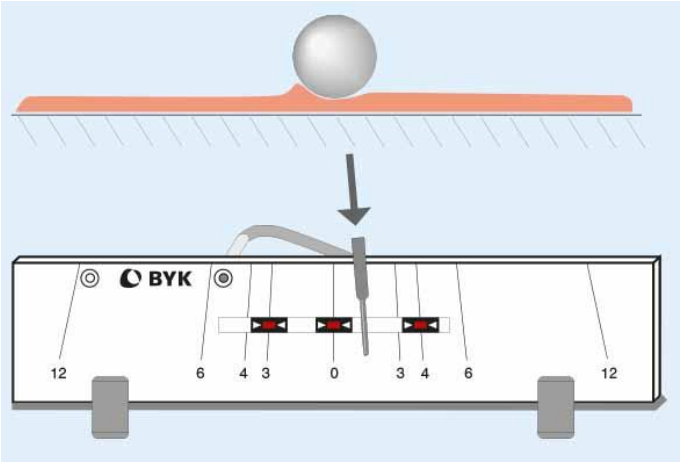

Fig. 1: Measurement principle of Pendulum Damping Test

The two pendulums described below have an open frame. Two balls are attached to the lower part, which serve as a rotating point.

3.1 Pendulum Damping with König Pendulum

The König pendulum has a triangular shape and rests on two tungsten carbide balls of 5 mm diameter being 30 mm apart (Fig. 2). The weight of the pendulum is 200 g. In the König test, the damping period is measured from 6° deflection to 3° deflection. At the 3° position, the count stops.

To adjust the natural oscillation frequency, a counterweight is attached to the vertical support rod. By sliding it up and down, the pendulum is adjusted at the time of manufacture. This calibration is performed on a flat glass plate, setting an oscillation period of 1.4 ± 0.02 sec. The glass plate is supplied as a reference tile for verification of the measuring system, whereby the mean value of three measurements is to be formed.

Fig. 2: byko-swing with König Pendulum

3.2 Pendulum Damping with Persoz Pendulum

The Persoz pendulum is rectangular and rests on two tungsten carbide balls, each 8 mm in diameter and 50 mm apart (Fig. 3). The total weight of the pendulum is 500 g. The damping period is measured between 12° and 4° deflection. At the 4° position, the count stops.

With the Persoz pendulum, there is no counterweight for adjustment, i.e. dimensions, total mass and center of gravity of the pendulum must be very precisely designed to achieve a natural oscillation frequency of 1sec and a damping period of 430 sec on a flat glass plate. The glass plate is supplied as a reference tile for verification of the measuring system, whereby the mean value of three measurements is to be formed.

Fig. 3: byko-swing with Persoz Pendulum

3.3 Comparison Table: König Pendulum versus Persoz Pendulum

	König-Pendulum	Persoz-Pendulum
Start position [°]	6	12
Stop position [°]	3	4
Period of oscillation on a glass plate [sec]	1,4 ± 0,02	1,0 ± 0,01
Total time for damping on a glass plate [sec]	250 ± 10	430 ± 15
Total number of oscillations on a glass plate	172 - 185	430 ± 15
Total mass [g]	200 ± 0,2	500 ± 0,1
Ball diameter [mm]	5 ± 0,005	8 ± 0,005
Ball distance [mm]	30 ± 0,2	50 ± 1,0

Since the measurement results are strongly influenced by the interaction between pendulum and coating and the elastic as well as viscoelastic properties of the coating, the measurement results of the two test methods cannot be compared with each other. Therefore, only the measurement results of one method should be compared with each other.

In the case of surfaces with a low coefficient of friction, the Persoz pendulum can skid, which will falsify the measurement results. Generally, the Persoz pendulum is used for "softer" coatings.

4 Test Conditions and Sample Preparation

In order to achieve comparable and reproducible measurement results, it is important to define both the environmental conditions (temperature and humidity) during the test as well as the substrate and coating thickness. The pendulum damping results of a coating on glass, metal or plastic will be very different.

The plates should be flat and free of distortion. They should be rigid or thick enough that they will not deform during testing. Metal or glass plates with a size of 100 mm x 100 mm x 5 mm are recommended.

The coating should be uniform and free of defects, whereas the measurement results are highly dependent on the coating thickness. The minimum coating thickness should be 30 µm. In addition, the coated specimens should be dried or baked according to the agreed specifications and conditioned at room temperature (23 ± 2 °C) and relative humidity (50 ± 5%) for at least 16 hours.

In the case of elastic or viscoelastic systems, the standard recommends that the panels be checked regularly over a specified period of time (days, weeks) in order to be able to record the values of any change due to further curing.

5 Typical Application Examples for Pendulum Hardness Test

5.1 Elasticity of clear coats for sealed hardwood floors

For sealed wood floors, the elastic properties of the coating are an important quality criterion. There is a wide range of different clear coats with high to matt gloss appearance. The requirement for the clear coat is that it should withstand a wide variety of loads. For example, if a table or chair is dragged across the floor, no friction marks should be visible afterwards. The same applies to the load during floor cleaning with a scrubber or brush. Also, here the hardwood floor should not show any marks afterwards. In other words, the challenge is to ensure that the clear coat is hard on the one hand, so that it is durable, and elastic at the same time, so that it can relax smoothly again after the load.

Fig. 4: Cleaning of hardwood floor

5.2 Elasticity of automotive coatings for exterior plastic parts

Especially automotive coatings on plastic substrates have to be elastic. Depending on the temperature (hot or cold weather), plastics change their size dimension much more than metal substrates. They flex much more under load and tend to deform rather than break. Therefore, more elastic components are used in the paint formulation than in automotive OEM painting for the body. Thus, polishing the surface of a plastic bumper is likewise a challenge for the clear coat. Its task is to exhibit great elasticity in order to cope with the scenarios described above, and at the same time it should not be too soft, as otherwise even a small stone chip would show up in a permanent mini dent in the paint surface that would no longer recover. The pendulum damping test simulates the stress of polishing movements very well and objectively assesses the elasticity of the clearcoat.

Fig. 5: Polishing of automotive part

6 Precision and Bias of Measurement Results

It is recommended to perform a test at three different locations on the same specimen plate. Both the mean value and the measured value range shall be documented in the test report. In order to evaluate the measurement results for significance in comparison tests, repeatability tests within one laboratory as well as reproducibility tests between different laboratories were performed and documented in the precision statements of ISO 1522 as well as ASTM D 4366.

6.1 Precision according to ISO 1522

The repeatability (r) is the difference between two repeat measurements at a confidence level of 95%. Both tests were performed by the same operator in one laboratory with two measurements each on one panel.

The reproducibility (R) is the difference between two test results from different operators and laboratories on the same test material at a confidence level of 95%. For each laboratory, the mean value of two test results was stated.

	Repeatablity (r)	**Reproducibility (R)**
König-Pendulum	5 oscillations	3 % variation of the mean value
Persoz-Pendulum	3 % variation of the mean value	8 % variation of the mean value

6.2 Precision according to ASTM D 4366

The precision statement in ASTM D4366 was performed for the Persoz method with five laboratories on six coated panels with a wide hardness range. For each sample panel, the average of 2-3 measurements was taken.

The precision results were the same as in ISO 1522 at an equal confidence level of 95%,.

7 Summary

The pendulum damping method is suitable for assessing the elasticity of coatings. The aim is to provide coatings with a specific resistance to deformation. The type of deformation to be evaluated in this method represents a rubbing on the surface (e.g. polishing of automotive paints - cleaning of hardwood floors). This type of wear can be objectively assessed with the pendulum damping method where a pendulum rests on two balls on the surface and is set into swinging.

An automated test is of great advantage, as repeatability can be significantly increased. The byko-swing offers a fully automated test procedure whereby the specimen is automatically positioned, the pendulum is brought into the proper displacement position and the damping time is automatically recorded. In addition, a high-quality acrylic protective cover (already pre-mounted) is part of the delivery scope to ensure that no air drafts can falsify the results during the test.

8 Standards

[1] DIN EN ISO 4618 Paints and varnishes – Terminology
[2] DIN EN ISO 1522 Paints and varnishes– Pendulum damping test
[3] ASTM D4366 Standard Test Methods for Hardness of Organic Coatings by Pendulum Damping Tests