ROTARY STEEL WOOL SCRATCH TESTERS

Abstract

The abrasion resistance of optically clear, thermoplastic coated and uncoated surfaces is of great interest to industry. Scratches not only alter surface properties, aesthetics and reflected image, but also can lead to premature failure. The identification and characterization of surface wear and tear is paramount in R&D, critical to quality and process control in meeting customer performance expectations. The rotary steel wool scratch test is a quick method that provides qualitative data to accurately predict service life of coatings and quantitative data needed to develop product performance specifications. Haze formation and material removal on transparent coated plastic surfaces, can be induced by various wear modes; yet, coated plastics in electronic devices fail due to surface scratching rather than abrasion wear by repetitive or continuous load conditions.

PCI Labs' Rotary Scratch Tester adds real value in the laboratory evaluation of abrasion wear resistance by offering reliable and standardized results. From changes in the optical properties due to scratching by steel wool (or other scrubbing media) on coated and uncoated surfaces, the measure of the material's long term scratch resistance can be obtained.

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INTRODUCTION

Hardness measures the resistance a material has to indentation and scratching. Abrasion wear is caused by a deformation process when an imposed force traverses across a softer surface over a period of time, causing indentations (material removal.) A scratch is a material failure due to an elastic, brittle and ductile deformation process. Many methods such as Brinell, Rockwell, Vickers, Mohs, Taber, Erichsen, Pencil, Micro-Indentation techniques, etc. have been devised to measure this material property, yield meaningful numerical results and identify a relationship with the strength of materials. Hardness is customarily determined by a Rockwell instrument, to indicate a material's resistance to surface deformation – thus, greater the hardness. Hardness, however is not an accurate indicator of wear resistance in thermoplastics. For example, nylon and acetal have outstanding wear resistance, which is not shown by a corresponding higher Rockwell number. Scratch resistance is the ability of the material to resist being worn away by a harder material and to maintain its original appearance and structure when subjected to rubbing, scraping, or scuffing. This material property is related to tensile strength, toughness, visco-elastic deformation, fracture, etc.

DISCUSSION

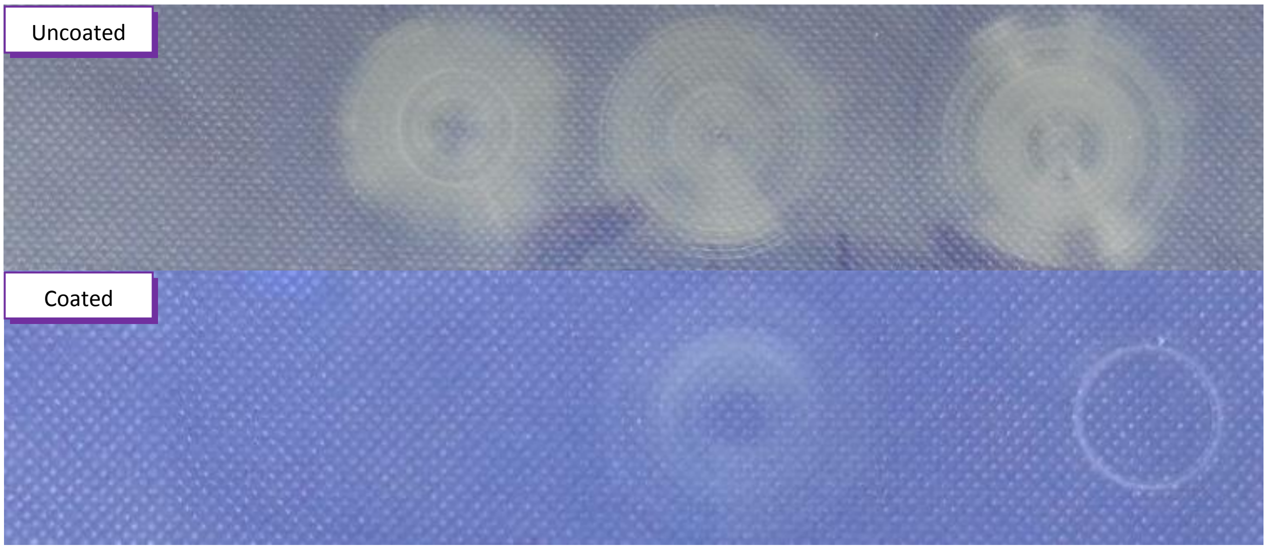
The standard test method for the determination of the resistance of organic coatings to abrasion produced by the Taber Abrader onto planar, rigid surfaces, while may be acceptable for materials which are homogeneous, when attempting to measure the scratch resistance of relatively thin coatings and/or films it becomes totally unreliable. Tests have demonstrated that there can be irreversible damage at a microscopic level, well before the scratch detection is determined by the Taber Test. The measured scratch resistance of thin films is dependent among other factors on coating chemistry (cross linking density, glass transition temperature), dry-film thickness, environmental factors of temperature and humidity, coating process capability, the abrasive materials used and the substrate over which the coating is applied. Stated in another way, scratch resistance is not an intrinsic property of the coating and usually means different things, depending on how the property is measured. When attempting to measure only the resistance of a material to surface scratching, the concept of "mar resistance" - the ability of a coating to resist damage caused by light abrasion, impact or pressure - comes into play. The abrasion wear mechanism is a complex mechanical damage process, test method dependent.

We are interested in surface scratching. The term "scratch resistance" then will be used to define the ability of a coating to withstand mechanical actions (abrasive wear) which tend to permanently change its surface appearance and structure. This permanent deformation is induced via a rotating steel wool, brush, abrasive paper, sponge, etc, and is a consequence of dynamic, curvilinear mechanical forces acting on the coated surface, resulting in surface scratches (repeated circular small scale patterns of damage) under controlled conditions. In curvilinear motion – with its two acceleration components – in contrast to rectilinear, the acceleration of a scratching particle moving with constant speed along a curve will not be zero. Thus, curvilinear motions are preferred to rectilinear in abrading substrate materials. As the steel wool presses ahead under load, the coating film is compressed and squeezed forwards and upwards at the leading edge and stretched in the scratch direction. The compressed material after a number of cycles, ruptures apart, is removed and pulled away from the substrate, creating circular grooved indentations.

The experimental scientist is not only interested in the measurement of a physical variable, but also of its control. The objectives of the experiment will direct the accuracy required, expense justified and level of human effort required. The experimental set-up with the least uncertainty is the most desirable from an experimental-accuracy standpoint. In quality measurements, great care, control of environmental variables and conditioning of substrates will usually produce the best results in the quickest possible way.

PCI curvilinear Scratch Testers provide the qualitative visual data and quantitative standards needed to develop performance specifications in the quickest way. Our intent was to develop a simple, reproducible and reliable test method to determine “real world” failure rates, on a broad range of coatings, plastic substrates, lenses and optical devices. This test is fast and can measure abrasion resistance with a variety of scrubbing materials under various loading conditions, so that a products’ appearance can be improved.

The test method involves rotating a 31.8 mm (1.25 in) square steel wool pad No 0000 (super fine, with a fiber width of ~0.03 mm; equivalent to 300-600 sandpaper) under load at 165.4 kPa (24 psi) or higher at 60 +/- 2 rpm. The weighted pad is usually rotated 25 times at about 1 rps to clearly show comparative wear performance.



Revolutions 0 5 50 100

Figure 1 Polycarbonate Substrate

Revolutions 0 5 50 100

Figure 2 Acrylic Substrate

Above are photographs of actual test panels which have been subjected to scratch testing using PCI Labs' automatic Scratch Tester-288.
On Figure-1, uncoated polycarbonate substrate (upper) and polycarbonate coated with PCI's Vueguard 901® high performance UV-curable coating (lower), is tested with 0000 steel wool, at 24 psi loading for 5, 50, and 100 revolutions at 60 rpm. On Figure-2 uncoated acrylic substrate (upper) and acrylic coated with Vueguard 901® (lower), is tested with 0000 steel wool, at 24 psi loading for 5, 50, and 100 revolutions at 60 rpm.

TEST DESCRIPTION

The characteristics for a good evaluation test are the correlation with actual field use in predicting product life and potential failure modes. For a useful test, the test procedure should be simple, reproducible, and quickly carried out. Another major criterion for a good test is that the results should be readily quantifiable, but in many instances this is difficult. However, if relative differences can be obtained as opposed to absolute values then, the relative results can be used to generate a ranking.

Although there are several potential wear failure modes including abrasion, adhesion, cavitation, corrosion and fatigue the most prevalent "real world" failure mode for optical lenses, films and other polymer based optoelectronic displays is the generation of scratches on the surface of the material by sharp objects. The scratched material has reduced surface aesthetics, becomes visually objectionable, affecting the optical performance of the device, by changing the light-transmitting and wide-angle light scattering properties of transparent plastics. As the most prevalent mode of failure is scratching, the use of steel wool as an abrasive medium is well suited to quickly generate scratches on the surface of a material in curvilinear motion. Through visual inspection of the scratches - under steel wool testing - a ranking of the scratch resistance of the materials can be made, as well as, repeating the same test in a variety of locations on the same surface, to determine a coating's uniform quality.

Samples are properly cleaned with alcohol (or dishwashing soap - aryl or alkyl sulfonate types) and conditioned at room temperature (23 ºC +/- 3 ºC) for no less than 24 hours prior to testing, to minimize any changes in properties due to the effects of temperature and relative humidity. A standard laboratory atmosphere of 23 °C +/- 1 ºC (73.4 °F) and relative humidity of 50% +/- 5% as per ASTM D-618-95, should be used.

The preparation of the standardized steel wool pad (by the same manufacturer,) by folding and with proper fiber orientation is critical for measurement. Cut a strip of (0000) steel wool, approximately 31.8 mm x 130 mm, 6.35 mm thick (1.25" x 5.1" long, .25" thick.) First, fold both ends of the long side in to touch, and then fold one half under the other by assuring that fibers are aligned the long way. The steel wool pad should be free of fibers or burrs. Attach it with a double sided 3M pressure sensitive tape 4 cm2 per pad. The steel wool pad must be first conditioned by placing a glass test sample under the steel wool abrasion tester. Condition pads for 250 cycles.

A ranking for optically clear coated materials can be attained by reporting the rotary Steel Wool Ratio (SWR) with the same formulations on different substrates.
It is calculated as the ratio of the haze difference between initial and final conditions of the coated test sample divided by the uncoated substrate, as follows:

SWR = ΔCoat / ΔSub

Where:

Δ Coat = final haze value of test coated sample – minus initial haze value of same test sample

Δ Sub = Final haze of uncoated substrate material – initial haze of the substrate at the same test conditions as coated sample.

The aforementioned formula may also be used with a benchmark coating (as standard,) to replace the substrate's denominator and assess relative abrasion performance between different coating formulations on the same substrate material. All haze measurements in accordance with ASTM- D 1003.

$$SWR = \Delta Coat / \Delta Std$$

Where:

Δ Coat = final haze value of test coated sample – minus initial haze value of same test sample

Δ Std = Final haze of standard coating – initial haze of standard coating.

The Rotary Steel wool test is applicable to:

- Rank optically clear coatings; same dry-film thickness on same substrate material
- Rank different optically clear materials; same coating (same dry-film thickness) on different substrates.
- Rank competitive coatings Vs. benchmark coating of same thickness

Further information regarding the durability of a coating with regard to scratching may be obtained through haze change measurements using ASTM D1003-00 (Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics). Measurements of haze and luminous transmittance can be made using a haze meter and/or spectrophotometer. Thus, the light transmitting and wide-angle light scattering properties of scratched transparent plastic materials can be evaluated.

This surface "scratch resistance" test is different than cutting through the coating to determine hardness using a pointed tool or stylus as in the Taber Shear/Scratch and the Clement test methods. Other test procedures which have been used to measure scratch or abrasion resistance, such as the Taber Abrasion Test (ANSI/ASTM D1044) or the "Falling Emery Test" (ASTM D673), do not meet all the characteristics of a "good" test, as they show very poor reproducibility. With the Taber Abrasion Test, although the test is easy to perform the failure mode does not correlate well with the general failure mode in actual service and as Dr. Kramer (Mobay Film Division) said "when you deal with scratch resistance, the numbers are so small the tests are meaningless"[3]. Further studies have found significant variability when applied to coated polycarbonate and not representative of real life conditions[4]. The "Falling Emery Test" has been used to demonstrate that CR-39[2] (allyl diglycol carbonate) is more scratch resistant than glass, which does not correlate well with actual experience[1,2].

TEST PROCEDURE

Scratch Resistance

This procedure may be used for assessing the scratch resistance of either coated or uncoated materials and establishing whether the scratch resistance of a material or coating is at an adequate level by using steel wool or other scrubbing materials. The Steel Wool Tester is one of the few abrasion tests that the test loads can be large >345 kPa and can simulate "real-life" damage.

Performance Coatings International Laboratories' Rotary Scratch Testers, are constructed so that scratch resistance may be measured using variable loads, typically of 12 and 24 pounds/square inch on the steel wool pad attached to a square testing pad of 1.25 square inches (6.45 square centimeters) and can be applied at increments of 1 psi. The 0000 steel wool on the testing pad is then rotated for five revolutions, after which the sample is visually inspected for scratches in the coating and rated. The test may then be repeated in other locations to determine uniformity of the coating. Even though, PCI uses for internal validations 0000 steel wool other scrubbing materials, such as brushes, sponges, abrasive papers, etc. may be used to simulate "real world" failure modes.

Haze Development

This procedure may be used for evaluating the resistance of transparent materials to surface scratching through the measurement of changes in optical properties. The resistance to surface scratching is measured by determining the change in haze which occurs after the test sample has been subjected to scratching by steel wool or other scrubbing materials.

Performance Coatings International Laboratories' Scratch Testers previously described are used for this evaluation, except that the number of cycles used is 250 rotations with a 4 pound/square inch load. After the sample has been subjected to scratching by steel wool, an integrating sphere photometer is used to measure the percentage of the transmitted light that is diffused by the scratched area. From this testing, a measure of the long term scratch resistance of materials may be obtained and correlated.

APPLICATIONS

Performance Coatings International Laboratories' Scratch Testers are available for sale. The devices are ideally suited for comparative testing, selection of materials, finishes and coatings. The testers can be utilized to establish both qualitative visual and quantitative standards and specifications. The units may also be employed to monitor the consistency and quality of the product with respect to established standards. The simplicity of performing the rotary steel wool scratch test means results are obtained quickly for maximum laboratory savings. Coated and uncoated surfaces may be tested for resistance to abrasion by other scrubbing materials. Most scrubbing materials are available and are optional attachments to the Scratch Testers.

[1] Chappel, R.W. and J.P.F.G. Newberry, The Optician, 530, November 19, 1965
[2] Chappel, R.W. and J.P.F.G. Newberry, The Optician, 530, November 19, 1965
[3] Ansel, T., Appliance Manufacturer, pg 71, August 1990
[4] Scolten, A., "Taber Test or Oscillating Sand", PCI Magazine, March 2004