Designation: D 7027 – 05

Standard Test Method for Evaluation of Scratch Resistance of Polymeric Coatings and Plastics Using an Instrumented Scratch Machine[1]

This standard is issued under the fixed designation D 7027; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method describes a laboratory procedure using an instrumented scratch machine to produce and quantify surface damage under controlled conditions. This test method is able to characterize the mar and scratch resistance of polymers by measuring many significant material parameters. The scratch-inducing and data acquisition process is automated to avoid user-influenced effects that may affect the results.

1.2 The values stated in SI units are to be regarded as standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—FLTM BN 108-13, ISO 1518 and ISO 12137-2 are related to this test method; the contents are significantly different from this method.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 618 Practice for Conditioning Plastics for Testing
D 638 Test Method for Tensile Properties of Plastics
D 1894 Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
F 2215 Specification for Balls, Bearings, Ferrous and Nonferrous for Use in Bearings, Valves, and Bearing Applications
G 99 Test Method for Wear Testing with a Pin-On-Disk Apparatus
G 171 Test Method for Scratch Hardness of Materials Using a Diamond Stylus

2.2 *ISO Standards:*[3]

ISO 1518 Methods of Test for Paints—Part E2: Scratch Test
ISO 12137-2 Methods of Test for Paints—Part E18: Determination of Mar Resistance using a Pointed Stylus
ISO 3290 Rolling Bearings: Balls—Dimensions and Tolerances

2.3 *Other Standards:*

FLTM BN 108-13 Resistance to Scratching[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *critical normal load*, *n*—the normal load at which whitening (see 3.1.10) of the material within the scratch groove first occurs.

3.1.2 *friction force*, *n*—the tangential force present at the interface between two bodies when one body moves or tends to move relative to the other, under the action of an external force. Depending on the penetration of the indenter into the test surface, friction force can be caused by sliding (relatively small displacement of material) or ploughing (gross removal/displacement of materials).

3.1.3 *mar resistance*, *n*—ability to resist surface damage from the light abrasion by small objects. Quantitatively, it can be characterized by the loss in gloss, increase in haze, or slight shift in gray level.

3.1.4 *normal load*, *n*—a load acted onto the scratch stylus that is imposed in a vertically downward direction while maintaining its perpendicularity with the direction of scratch.

3.1.5 *scratch depth*, *n*—the vertical distance to be measured from the trough of the scratch groove to (a) its peak or (b) to the undisturbed specimen surface.

3.1.6 *scratch resistance*, *n*—ability to withstand damage that is accompanied by the gross deformation typically associated with sharp objects that may involve compressing, ploughing, and shearing off of material. Quantification can be accomplished through the measurement of scratch depth (3.1.5), scratch width (3.1.7) and other geometric characteristics of the scratch.

3.1.7 *scratch width*, *n*—the horizontal distance between the two peaks on both sides of the scratch groove.

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.
Current edition approved June 1, 2005. Published June 2005.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[4] Available from Ford Motor Company, Central Laboratories, 15000 Century Drive, Dearborn, MI 48120.

3.1.8 *scratching*, *v*—mechanical removal, or displacement, or both of material from a surface by the action of abrasive particles, or protuberances, or both sliding across the surfaces.

3.1.9 *scratching coefficient of friction*, *n*—the ratio of the friction force (3.1.2) to the normal load (3.1.4). This coefficient is a measure of the resistance of a material to scratching. For tests conducted under constant load, two distinct quantities may be characterized, the static and kinetic coefficients. The static coefficient is related to the friction force measured prior to the movement of the scratch stylus while the kinetic coefficient is related to the constant friction force measured in sustaining this movement. This quantity is not equivalent to the coefficient of friction, which is obtained in accordance with Test Method D 1894 and is similar to the stylus drag coefficient as defined in Test Method G 171.

3.1.10 *whitening*, *n*—the visible damage along the scratch groove of the surface caused by microcracking, voiding, crazing, and debonding.

4. Summary of Test Method

4.1 This test method utilizes an automated scratch machine to administer controlled scratch tests on polymeric specimens. Two basic test modes (Test Modes A and B) are presented.

4.1.1 *Test Mode A*—A scratch is applied onto the specimen surface under an increasing load from 2 to 50 N ± 0.1 N over a distance of 0.1 m ± 0.0005 m at a constant rate of 0.1 m/s ± 0.0005 m/s - average. This test mode is intended to determine the critical normal load at which whitening will occur for a material system. For materials that do not show any whitening, the normal load at which a predetermined scratch width exists will be used as a basis for comparison. To compare and rank different materials, the normal load shall be plotted as a function of the scratch width.

4.1.2 *Test Mode B*—A scratch is applied onto the specimen surface under a constant load of 30 N ± 0.1 N over a distance of 0.1 m ± 0.0005 m at a constant rate of 0.1 m/s ± 0.0005 m/s - average. This test mode is intended to evaluate the homogeneous response of the material and establish the scratching coefficient of friction.

4.2 Scratched surface can be visually inspected or by using evaluation tools to study the surface damage. For Test Mode A, the critical normal load is determined by the onset of the whitening of the material due to scratch. Measurement of the scratch widths, or depths, or both shall also be taken to aid the quantification of scratch resistance.

4.3 Scratching coefficient of friction as defined in 3.1.9 can be computed for material characterization using the friction force and normal load data recorded during tests.

5. Significance and Use

5.1 Scratch tests are performed on specimens:

(1) to evaluate the scratch or mar resistance of a particular material,

(2) to rank the relative scratch resistance of different materials, or

(3) to determine the scratching coefficient of friction of materials.

5.2 Since polymers exhibit mechanical properties that are strongly dependent on temperature, the test method prescribed herein is designed to yield reproducible results when users perform tests under the similar testing environment and on specimens of the same material and surface texture that are subjected to the same conditioning procedures.

5.3 Certain polymers are self-healing (recoverable) when subjected to scratches and other physical deformations because of their viscoelastic and relaxation properties. It is important to note the difference between the instantaneous (if readily measurable) and the post-scratch damages and appropriately compare results to ensure reproducibility.

5.4 "Whitening" of the scratched surface is a key damage mechanism that has prompted much concern in automotive and other applications where surface aestheticism is important. This type of damage is undesirable because it is evident to human eyes. The critical normal load at which this phenomenon appears serves as a benchmark in ranking material performance.

5.5 For polymers that do not exhibit whitening, a scratch groove from severe ploughing is still highly noticeable. In such cases, the normal load required to achieve a certain scratch width shall be reported to characterize scratch visibility and scratch resistance. The critical scratch width shall be decided by users in accordance with the specific material and remains the same throughout a set of tests for a consistent comparison. The variation of the scratch width as a function of the applied load shall also be plotted for comparison purposes.

6. Apparatus

6.1 *General Description*—The instrumented scratch machine[5] described here has been developed at Texas A&M University under the auspices of the Scratch Behavior Consortium; a schematic of the scratch machine is shown in Fig. 1. The instrument consists of a sample stage, clamping devices, a spring-load/dead-load system, and a horizontal motion servo system. Optional systems such as load and position sensing system, data acquisition and computer systems can be included when position and load data are required. An environmental chamber can also be added for non room-temperature (23 ± 2°C) tests. For post-scratch study, evaluation instruments like optical microscopes, flatbed scanners and image capturing tools can separately be used.

6.2 *Spring-Load Mechanism*—The instrument is a stylus-type scratcher in which a 1-mm-diameter spherical tip is used to scratch the surface of a flat specimen. It consists of a sample stage with dimensions of 305 by 305 mm^2 on which test specimens can be anchored. The spring-load driven mechanism, capable of generating 0 to 75 N of normal load, exerts the force onto the scratch stylus, either at a constant magnitude or increasingly to a desired magnitude.

6.3 *Dead-Load Mechanism*—The dead-load mechanism, as presented in Fig. 1, is similar to the setup of the spring-load mechanism as in 6.2, except that it uses dead weights for the

[5] The sole source of supply of the apparatus known to the committee at this time is Surface Machine Systems, LLC, 2151 Harvey Mitchell Parkway, Suite 223, College Station, TX 77840. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee [1], which you may attend.

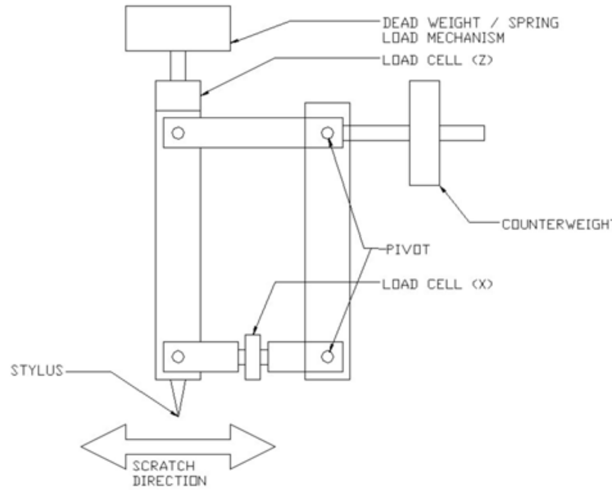

FIG. 1 Schematic of the Instrumented Scratch Machine

normal load during scratch. This setup can also be used for Test Mode B, where a constant load is required.

6.4 *Horizontal Motion Servo System*—A high-precision motor controlled via microprocessor, actuates the scratch stylus. The horizontal speed of the scratch stylus can be set at a constant rate between 0 to 400 mm/s or with a constant acceleration from 0 to 400 mm/s^2.

6.5 *Load and Position Sensing System (optional)*—If required, the instrument can be incorporated with devices to monitor the normal load, friction force, instantaneous scratch depth and horizontal position. The friction force acting on the stylus shall be measured with an accuracy of 0.1 N. The data acquired for depth, horizontal position and velocity of the stylus shall have accuracy of 0.5 µm, 5 µm and 0.0005 m/s (average), respectively.

6.6 *Data Acquisition and Computer Systems (optional)*—Connections from the sensing system to the computer system must be insulated against electromagnetic interference to ensure clean and reliable data. The computer system shall have the capability to collect the force and position data. The minimum sampling rate for the data acquisition system shall be kept at 1000 data points per second for reliable and accurate data.

6.7 *Environmental Chamber (optional)*—An environmental chamber with heating and cooling controls allows experiments to be performed from –50 to 100°C.

6.8 *Evaluation Instruments*—Other than visual inspection, the scratch grooves can be further examined with optical microscopes, flatbed scanners, or interferometers, or a combination of the three, for measuring scratch widths and depths. Since the capability and sensitivity of each device are different, it is required that the adopted method of evaluation be reported. For the purpose of quantifying whitening, other instruments that are capable of measuring reflected light intensity in the scratch groove can be used. The basic requirement for any instrument is that light conditions shall be controlled to have the sensitivity to detect the whitening point within 0.05 mm.

6.9 *Stylus Tip*—The setup of the scratch machine provides the added flexibility of allowing the interchangeability of stylus tip in their material and geometry. The material of the scratch stylus tip shall be stainless steel and its shape shall be spherical with a diameter of 1 mm. Surface quality of the tip shall be of Grade 10 or better, in accordance with Specification F 2215 or ISO 3290.

NOTE 2—Other materials for the stylus tip are acceptable so long as they have higher indentation hardness than the test material. If the relative hardness of the materials is significantly different from the stainless steel, the resulting scratch test data will be dissimilar as those yielded by a stainless steel spherical tip. Using a tip of other geometry is optional but their results shall not supersede those from the spherical tip tests.

7. Hazards

7.1 The scratch carriage could suddenly accelerate to 400 mm/s; precaution shall be taken to avoid having hands, fingers, and loose clothing pinched by the moving part.

7.2 When performing tests at extreme temperatures, ensure that thermally insulated gloves are used in handling specimens.

8. Test Specimens and Sample Preparation

8.1 *Materials*—The test method can be applied to a variety of polymeric and coating materials. The materials must be able to be prepared to the desired dimensions and able to withstand the stresses imposed during the test without failure or excessive fracture. The materials being tested shall be described by dimensions, surface finish, material type, form, composition, processing treatment and, when appropriate, indentation hardness (see Test Method G 99).

8.2 *Tensile Specimens*—Injection-molded tensile bars as specified in Test Method D 638 (Test specimen I-III) are acceptable for use with this test. Typical thickness shall be between 3 and 10 mm. Since the scratch length for different test modes is taken to be 100 mm, the specimen shall be at least 140 mm in length to provide enough area for clamping at both ends. Experiments have shown that thickness will affect scratch properties and care shall be taken to ensure that the thicknesses of different specimens are consistent within the tolerance specified in Test Method D 638.

8.3 *Plaque Specimens*—A plaque, at least 140 mm in length, shall be used. It is possible to make multiple scratches on the same plaque so long as the grooves do not affect one another and the distance between the two neighboring grooves shall be no less than 2 mm.

8.4 *Sampling Size*—At least five specimens (or five runs) shall be tested to ensure repeatability.

8.5 *Surface Finish*—For material comparison, test specimens shall have the same surface texture and color, unless the experiment is performed to investigate the effect of surface texture and color. This is especially important for the detection of whitening in the scratch path as certain colors and grained textures tend to hide the surface damage better than others.

9. Preparation of Apparatus

9.1 *Scratch Stylus Tip*—Regular inspection of scratch stylus tip for its sphericity shall be done with an optical microscope. If the surface quality of the stylus tip fails to satisfy the tolerances as stated in Specification F 2215 or ISO 3290, the tip shall be replaced. The frequency of inspection will depend on the material of the tip and test specimen.

10. Calibration and Standardization

10.1 Scratch machine, data acquisition system, and any associated electronic equipment shall be maintained at a constant temperature (±2°C) for a period of at least 24 hours prior to and during testing. The test equipment shall be located in an environment with the standard laboratory atmosphere as specified in Practice D 618.

10.2 Prior to conducting any test, verification, or calibration, or a combination of the three, the scratch machine and associated electronic equipment shall be powered on and allowed to warm up for a period of not less than thirty minutes.

10.3 Before any test, the accuracy of the load and position sensors shall be verified. The verification procedure is outlined as the last step of the calibration process in 10.4. Sensors for the normal load and friction force shall operate at an accuracy of ±0.1 N while the vertical and horizontal position sensors shall also be checked for an accuracy of ±0.5 µm and ±5 µm, respectively. If the accuracy of the load and position sensors be found out of specification, calibration must be performed.

10.4 For calibration, precision weights shall be used to calibrate load sensors while standard gage blocks are used to calibrate position sensors. Calibration shall be performed with at least five data points: two above, two below, and one at the average value of the sensor's effective range. After calibration, the accuracy of the load and position sensors must be reverified prior to performing tests.

11. Conditioning

11.1 To conduct scratch tests under the standard laboratory atmosphere, the conditioning practice, Procedure A as specified in Practice D 618 shall be followed. Particularly for materials whose mechanical properties can be affected by relative humidity, the conditioning practice must be strictly adhered. For other testing conditions, users shall refer to Practice D 618 for the recommended conditioning procedures.

11.2 Prior to the execution of the tests, the surface of the specimen and the scratch stylus are to be inspected for any contaminants and cleaned if necessary. Only cleaners that do not alter the test material and its surface characteristics shall be used for cleaning specimens and the scratch stylus. Sufficient time shall be allowed for wet cleaning agents to thoroughly dry before the actual test is performed.

12. Procedure

12.1 Place the specimen on the test stage and secure it with lockable clamps. Make sure that the specimen is flat and its surface is clean. Move the test specimen until the scratch stylus is directly above the start position of the scratch path and tightly secure the specimen. Check if the stylus tip is clean and free of foreign materials and damage.

12.2 If scratch tests are to be conducted at temperatures other than the room temperature (23 ± 2°C), an environmental chamber shall be used to maintain the stylus and the specimen at the desired temperature. Prior to testing, the stylus and specimen shall be conditioned in the environmental chamber for not less than thirty minutes.

12.3 Define the start and end positions of the scratch path. Select the appropriate test mode and input the necessary parameters such as scratch rate and normal load.

12.4 Ensure that load and position sensing and data acquisition systems are operational when real-time data are to be collected.

12.5 Begin the scratch process.

12.6 Examine the scratch groove of the test specimen under a calibrated microscope, or a profilometer, or both and quantify the scratch width and depth. A flatbed scanner can also be used to determine scratch widths.

12.7 When using Test Mode A and whitening is observed, the point of the first occurrence along the scratch path shall be noted. This shall be visually accomplished or through the assistance of optical instruments and image analysis. Correspondingly, the critical normal load shall be determined and used for material comparison and ranking. To illustrate the difference in surface damage, Fig. 2(a) shows no whitening on polycarbonate while whitening is observed for polypropylene as shown in Fig. 2(b).

13. Calculation or Interpretation of Results

13.1 Scratch width, or depth, or both shall be quantified using flat-bed scanners, optical microscope or other appropriate profile analysis instruments, as specified in 8.8 of Test Method G 171. The width and depth measured shall provide critical dimensions for analyzing the scratch path. It shall be noted, however, that comparing the scratch width provides more consistent results than scratch depth, as the latter tends to significantly fluctuate even under constant loads. If there is a need to use scratch depth as a basis of comparison, users must clearly indicate how the scratch depth is measured, based on the definition provided in 3.1.5.

13.2 Incorporating the depth and load sensing option to the scratch machine allows the instantaneous or real time data such as scratch depth (3.1.5b), friction force and normal load to be captured during the scratch process and these data can then be graphically plotted for study. As examples, curves representing the applied normal load, the measured friction force and the computed scratching coefficient of friction during the scratch