



Designation: D7869 – 17

# Standard Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings<sup>1</sup>

This standard is issued under the fixed designation D7869; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This practice specifies the operating procedures for a controlled irradiance xenon arc light and water apparatus. The procedure uses one or more lamp(s) and optical filter(s) to produce irradiance similar to sunlight in the UV and visible range. It also simulates the water absorption and stress cycles experienced by automotive exterior coatings under natural weathering conditions. This practice has also been found applicable to coatings on other transportation vehicles, such as aircraft, trucks and rail cars.

1.2 This practice uses a xenon arc light source with specified optical filter(s). The spectral power distribution (SPD) for the lamp and special daylight filter(s) is as specified in **Annex A1**. The irradiance level used in this practice varies between 0.40 and 0.80 W/(m<sup>2</sup>·nm) at 340 nm. Water is sprayed on the specimens during portions of several dark steps. The application of water is such that the coatings will absorb and desorb substantial amounts of water during testing. In addition, the cycling between wet/dry and warm/cool will induce mechanical stresses into the materials. These test conditions are designed to simulate the physical and chemical stresses from environments in a subtropical climate, such as southern Florida.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *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.*

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.27 on Accelerated Testing.

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## 2. Referenced Documents

2.1 *ASTM Standards*:<sup>2</sup>

**D4517** Test Method for Low-Level Total Silica in High-Purity Water by Flameless Atomic Absorption Spectroscopy

**G113** Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials

**G147** Practice for Conditioning and Handling of Nonmetallic Materials for Natural and Artificial Weathering Tests

**G151** Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

**G155** Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials

## 3. Terminology

3.1 Definitions applicable to this standard can be found in Terminology **G113**.

3.2 *transportation coatings, n*—exterior coatings used for vehicles subjected to natural weathering conditions such as automobiles, aircraft, trucks, rail cars, etc.

## 4. Summary of Practice

4.1 Test specimens are exposed to specific test conditions designed to simulate the physical and chemical stresses from environments in a subtropical climate, such as southern Florida. The test conditions consist of a primary test cycle and a sub-cycle. The primary test cycle includes two long water exposures and a single, long light exposure with precise spectral match to daylight as described in **Annex A1**. It is designed to reproduce water penetration failures, such as adhesion, blistering and diffusion of small molecules (**1**).<sup>3</sup> The sub-cycle consisting of shorter alternating water and light

<sup>2</sup> 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.

<sup>3</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.

exposures is designed to simulate cyclic stresses such as cracking and surface erosion. These two cycles are designed to replicate the common types of failures driven by the interaction of photo-oxidation during daylight and hydrolysis during water exposure that are seen in a subtropical climate such as gloss loss, color change, adhesion, blistering and cracking (2).

## 5. Significance and Use

5.1 This test procedure is used to simulate the physical and environmental stresses that a coating for exterior transportation applications (for example, automotive) is exposed to in a subtropical climate, such as southern Florida. It has been found that such a subtropical climate causes particularly severe deterioration of such coatings. The long water exposures and wet/dry cycling found in southern Florida are particularly important for this deterioration, in addition to the high dosage of solar radiation (3). This practice was developed to address the deficiencies of historical tests used for transportation coatings, especially automotive coatings (4).

NOTE 1—This test procedure was developed through eight years of cooperative testing between automotive and aerospace OEM's, material suppliers, and test equipment manufacturers. See References for published papers on this research.

## 6. Apparatus

6.1 The *xenon arc light and water apparatus* shall comply with Practice G155.

6.1.1 The *xenon arc light and water apparatus* shall have an uninsulated black panel thermometer as described in Practice G151 unless otherwise agreed upon by contractual parties

6.1.2 The *xenon arc light and water apparatus* must be able to control irradiance at 340 nm, relative humidity, uninsulated black panel temperature and chamber temperature, and provide water spray on the front of the specimens.

6.2 *Mass balance*—with a resolution of at least 0.1 g.

## 7. Reagents and Materials

7.1 *Sponge*. See Annex A2 for more detailed specifications.

7.2 *Purified Water*, as specified in Practice G155 and 8.2.

## 8. Apparatus Setup

8.1 Maintain and calibrate the apparatus according to manufacturer's instructions.

8.2 *Water Spray*—The water for spray and humidification shall be of the same quality listed in Practice G155 and shall leave no objectionable deposits or stains on the exposed specimens. The water shall have less than 1 mg per litre (1 ppm) total dissolved solids and it shall have less than 0.1 mg per litre (0.1 ppm) silica.

NOTE 2—Silica levels should be determined using Test Method D4517 or equivalent. A combination of deionization and reverse osmosis treatment can effectively produce water with the desired purity. In certain cases some samples could exude materials into the chamber that can promote deleterious effects on other samples.

8.3 Qualify the sponges used for the water uptake per the procedure in Annex A2. For each xenon arc light and water apparatus, verify the water uptake capability in accordance with the procedure in Annex A3 before placing it into service

and at least once per year thereafter. Follow the recommendations of the manufacturer of the xenon arc light and water apparatus for additional checks, if any.

8.4 Fit the xenon arc light and water apparatus with a special daylight filter(s) in accordance with the requirements of Annex A1.

NOTE 3—Contact the xenon arc light and water apparatus manufacturer for the proper optical filter(s) required. Follow the manufacturer's recommendations for optical filter maintenance.

8.5 Other optical filters may be used by mutual agreement between the contractual parties.

NOTE 4—Minor differences in the resultant spectral power distribution (especially in the short wavelength UV region) can have an impact on the test results. Follow the manufacturer's recommendations for xenon arc lamp and optical filter maintenance (5).

## 9. Test Procedure

9.1 Refer to Practice G147 for specimen preparation, conditioning and handling. All test specimens must be clean and free from fingerprints or other surface contaminants before testing. Prepare a specimen for exposure to fit the specimen mounting fixture being used, if any. Follow the manufacturers' guidelines for specimen size and mounting.

9.1.1 Seal any cut edges on the test specimens if required, as agreed between contractual parties. For example, (a) rust and corrosion products from the cut edges of metal panels may stain the test specimens, (b) by-products from the cut edges of plastic substrates may leach out and contaminate test specimens, and (c) other panels may not require any edge sealing at all.

NOTE 5—Air-dry primers, plastic barrier tapes and silicone sealants have often been found suitable for edge sealing.

9.2 Fill all unused specimen positions in the xenon arc light and water apparatus' exposure area with inert specimens (for example, anodized aluminum panels) to maintain desired airflow.

NOTE 6—Refer to the manufacturer's instructions for proper operation of the apparatus.

9.3 Program the xenon arc light and water apparatus to run the exposure cycle shown in Table 1 and in accordance with manufacturer's instructions. The duration of the test in terms of number of cycles, hours, or radiant dosage shall be agreed upon by contractual parties.

9.4 Specimens shall be repositioned at a minimum of every two weeks of operation to improve uniformity of exposure. See Practice G151, Appendix X2 for more specific guidance and figures on repositioning of specimens in both rotating rack and flat array xenon arc light and water apparatus.

9.4.1 Specimens in a rotating rack apparatus shall be repositioned to the position immediately above it; specimens in the top position shall be repositioned to the bottom position.

9.4.2 Specimens in a flat array apparatus shall be repositioned to the position immediately to the left; specimens in the left-most position shall be repositioned to the right-most position, with front-back and back-front repositioning if applicable.

**TABLE 1 Exposure Cycle**

Step Number	Step Minutes	Function	Irradiance Set Point <sup>A</sup> at 340 nm W/(m <sup>2</sup> ·nm)	Black Panel Temperature Set Point <sup>A</sup>	Chamber Air Temperature Set Point <sup>A</sup>	Relative Humidity Set Point <sup>A</sup>
1	240	dark + spray	—	—	40°C	95 %
2	30	light	0.40	50°C	42°C	50 %
3	270	light	0.80	70°C	50°C	50 %
4	30	light	0.40	50°C	42°C	50 %
5	150	dark + spray	—	—	40°C	95 %
<b>6</b>	30	dark + spray	—	—	40°C	95 %
<b>7</b>	20	light	0.40	50°C	42°C	50 %
<b>8</b>	120	light	0.80	70°C	50°C	50 %
<b>9</b>	10	dark	—	—	40°C	50 %
10	Repeat subcycle steps 6 to 9 (shown in bold) an additional 3 times (for a total of 24 h = 1 cycle).					

<sup>A</sup> The set point is the target condition for the sensor used at the operational control point and is programmed by the user. When the exposure cycle calls for a particular set point, the user programs the apparatus to use that exact number. Operational fluctuations are deviations from the indicated set point during equilibrium operation. The maximum allowable operational fluctuation during equilibrium conditions for the exposure cycle above is  $\pm 0.02$  W/(m<sup>2</sup>·nm) for irradiance,  $\pm 2.5^\circ\text{C}$  for black panel temperature,  $\pm 2^\circ\text{C}$  for chamber air temperature, and  $\pm 10$  % for relative humidity.

NOTE 7—Specimen repositioning in 9.4.1 and 9.4.2 is required to compensate for variations in light, water, relative humidity and temperature within the test chamber.

9.5 The test shall be interrupted for repositioning and specimen evaluations only during a step without water spray.

## 10. Report

10.1 The test report shall conform to Practice G151. The report shall also include the average of three water collection

measurements for each position in the xenon arc light and water apparatus, in accordance with Annex A3.

## 11. Keywords

11.1 accelerated; automotive; coatings; durability; exposure test; irradiance; lightfastness; weathering; xenon arc

## ANNEXES

### (Mandatory Information for Equipment Manufacturers)

#### A1. DAYLIGHT FILTER IRRADIANCE LIMITS BY WAVELENGTH

A1.1 Conformance to the spectral power distribution in Table A1.1 is a design parameter for a xenon-arc source with the different optical filters provided. Manufacturers of equipment claiming conformance to this standard shall be responsible for determining conformance to the spectral power distribution table for all lamp/filter combinations provided, and provide information on maintenance procedures to minimize any spectral changes that may occur during normal use.

Wavelength Band (nm)	Total Irradiance Over Indicated Wavelength Band (W/m <sup>2</sup> )	
	Minimum	Maximum
$\lambda < 290$	0.00	0.005
$290 \leq \lambda < 295$	0.00	0.01
$295 \leq \lambda < 300$	0.01	0.04
$300 \leq \lambda < 305$	0.10	0.20
$305 \leq \lambda < 310$	0.38	0.56
$310 \leq \lambda < 320$	2.29	3.10
$320 \leq \lambda < 330$	4.76	5.82
$330 \leq \lambda < 340$	6.84	7.56
$340 \leq \lambda < 350$	7.69	9.40
$350 \leq \lambda < 360$	8.13	11.00
$360 \leq \lambda < 370$	8.32	12.47
$370 \leq \lambda < 380$	8.30	13.83
$380 \leq \lambda < 390$	8.64	14.40
$390 \leq \lambda < 400$	9.23	17.15

Note: Irradiance in W/m<sup>2</sup> normalized to 0.80 W/(m<sup>2</sup>·nm) at 340 nm.

(Mandatory Information)

**A2. SPONGE QUALIFICATION PROCEDURE**

A2.1 Cut a section of the homogeneous sponge material to a maximum size of 57 mm wide, 127 mm long and 19 mm thick. Both sides of the sponge shall have the same water absorbance capability. Do not use multi-layer sponges.

A2.2 Weigh a damp sponge.

A2.2.1 Thoroughly saturate the cut sponge with water by soaking it in at least 2 L of water at room temperature ( $23 \pm 3^\circ\text{C}$ ) for a minimum of 1 min. or until it has reached full saturation. Different types of sponges will take different times to reach full saturation.

A2.2.2 Wring sponge tightly by hand as shown in Fig. A2.1 until no water drips are observed over a period of 15 seconds. Weigh it to the nearest 0.1 g on a calibrated balance capable of at least 100.0 g total weight. The preferred type of sponge for this test method will weigh between 20.0 and 30.0 g after removing excess water.

A2.2.3 Tare the balance to zero and remove the damp sponge from the balance. Subsequent weighing of the sponge will thus record only the additional water absorbed into the sponge.

A2.3 Weigh a saturated sponge.

A2.3.1 Saturate the sponge again in a minimum 2 L of room temperature water by keeping the sponge totally immersed for a minimum of 1 min.

A2.3.2 After a minimum of 1 min., remove the sponge from the water and lightly hold it vertically over the water container as shown in Fig. A2.2. Continue holding it until the sponge has at most, one water drop per 15 seconds coming from the bottom of the sponge.

A2.3.3 Turn the sponge horizontally as shown in Fig. A2.3 to prevent any more water loss and place it on the tared balance. This will show the additional mass of water absorbed beyond the mass of just the damp sponge. Record the mass.

A2.3.4 Repeat steps A2.3.1 – A2.3.3 two additional times and determine an average mass of water held by the sponge for the three runs. This will define the saturation capacity of the sponge (mass of saturated sponge minus mass of damp sponge).

A2.4 Acceptance criteria for the saturation capacity of the sponge is as follows:

- Minimum: 40.0 grams
- Preferred: 50.0 grams
- Maximum: no maximum

A2.5 If the criterion in Step 4 (A2.4) is not met, a new source of sponge material must be obtained for testing.



**FIG. A2.1 Removing Water from Sponge through Wringing by Hand**



**FIG. A2.2 Holding Sponge Vertically**



FIG. A2.3 Holding Sponge Horizontally

(Mandatory Information)

**A3. XENON ARC LIGHT AND WATER APPARATUS WATER SPRAY SYSTEM QUALIFICATION PROCEDURE**

A3.1 Confirm spray nozzles are operational and spray system is programmed per the manufacturer's instructions. Follow the apparatus manufacturer's requirements for minimum water pressure for correct operation of the xenon arc light and water apparatus. Clean, repair and adjust water flow or pressure as needed. In order to prevent artificially high sponge absorption values, the apparatus (and any sponge specimen holders which may be used) shall be designed to only allow water absorption from the front, lamp-facing side of the sponge. Water spray and water run-off from other specimen areas shall be prevented from reaching the sponge top, sides, and back. See [Appendix X3](#) for examples of sponge specimen holder designs that fulfill the requirements of this section [A3.1](#).

A3.2 Prepare sponges in accordance with [Annex A2](#), Step 1 ([A2.1](#)).

A3.3 Wet the sponges thoroughly with water with a purity as specified in [8.2](#). Do not use tap water. Water should be dripping from sponges.

A3.4 Wring sponge tightly by hand as shown in [Fig. A2.1](#) until no water drips are observed over a period of 15 seconds. This will result in a damp sponge.

A3.5 Weighing sponges:

A3.5.1 If specimen holders are used, place damp sponges in specimen holders with each sponge mounted within a single exposure window. Wipe the specimen holders dry and weigh and record mass for each specimen holder (including the sponge) to the nearest 0.1 g.

A3.5.2 If no specimen holders are used, weigh and record mass for each sponge to the nearest 0.1 g.

A3.6 Sponges shall be in the same orientation as a test specimen when mounted in the xenon light and water apparatus. Mount the sponges as follows:

A3.6.1 One in each tier of the rotating rack xenon arc light and water apparatus (for example, upper, middle, and lower positions). Start the sponges directly opposite from the spray nozzles (that is, on the other side of the rack, away from the nozzles).

A3.6.2 One in each of three areas on the tray of a flat array xenon arc light and water apparatus (that is, the top-left, middle-middle, and bottom-right positions).

A3.7 Set and run the following cycle in xenon arc light and water apparatus as per manufacturer's instructions: 5 min. dark + spray at 50°C chamber air temperature, front spray only.

A3.8 Weighing sponges again:

A3.8.1 If specimen holders are used, remove specimen holders from the xenon arc light and water apparatus. Wipe the specimen holders dry and weigh and record mass for each specimen holder (including the sponge) to the nearest 0.1 g.

A3.8.2 If no specimen holders are used, remove the sponges from the xenon arc light and water apparatus and weigh and record mass for each sponge to the nearest 0.1 g.

A3.9 Calculate the amount of water uptake, to the nearest 0.1 g. Water uptake is the mass found in Step 8 ([A3.8](#)) minus the mass found in Step 5 ([A3.5](#)).

A3.10 Repeat Steps 4–9 ([A3.4](#) – [A3.9](#)) two additional times for a total of three measurements for each position of the xenon arc light and water apparatus, as identified in Step 6 ([A3.6](#)). Average the three measurements for each position to calculate



the water uptake produced by that position of the xenon arc light and water apparatus.

A3.11 The acceptance criterion for water uptake in a xenon arc light and water apparatus is as follows; the average for the three sponge measurements in a particular position of the xenon arc light and water apparatus must meet this criteria:

Minimum: 10.0 grams  
Maximum: no maximum

There is no maximum water delivery defined. The goal is for the coating system to achieve saturation. If the minimum water delivery is achieved per the above, the coating system will be saturated under the stated cycle.

NOTE A3.1—If the minimum water uptake requirements cannot be met, consult with the apparatus manufacturer for instructions on apparatus modifications that can be implemented to meet the minimum requirements.

## APPENDIXES

### (Nonmandatory Information)

#### X1. EXAMPLE OF SPONGE DATA FOR A XENON ARC LIGHT AND WATER APPARATUS

X1.1 *Example X1.1*—A xenon arc light and water apparatus that meets the requirements of Annex A3 (see Table X1.1).

X1.2 *Example X1.2*—A xenon arc light and water apparatus that DOES NOT meet the requirements of Annex A3 (see Table X1.2).

TABLE X1.1 Xenon Arc Light and Water Apparatus Example Sponge Data

Measurement #	Position 1 for example, upper tier or top left area of tray (g)	Position 2 for example, middle tier or middle area of tray (g)	Position 3 for example, bottom tier or bottom right area of tray (g)
1	18.3	26.0	17.5
2	22.0	31.2	19.3
3	23.1	29.6	19.6
Average	21.1	28.9	18.8

Note: This example shows a xenon arc light and water apparatus that meets the requirements of Annex A3, since the average of each position is at least 10.0 g.

TABLE X1.2 Xenon Arc Light and Water Apparatus Example Sponge Data

Measurement #	Position 1 for example, upper tier or top left area of tray (g)	Position 2 for example, middle tier or middle area of tray (g)	Position 3 for example, bottom tier or bottom right area of tray (g)
1	9.1	10.1	7.5
2	11.2	9.4	8.3
3	10.3	9.7	8.6
Average	10.2	9.7	8.1

Note: This example shows a xenon arc light and water apparatus that DOES NOT the requirements of Annex A3, since the average of each position is NOT at least 10.0 g.

### (Nonmandatory Information)

#### X2. EXPLANATION OF RATIONALE FOR STEPS IN THE CYCLE DEFINED IN Table 1

##### INTRODUCTION

The conditions for each step in the cycle are based on data collected over ten years of exposure tests in both Florida and accelerated testers. These tests were performed at multiple locations and involved multiple cooperating companies, including automotive OEMs, coating suppliers and test equipment suppliers (2).

##### X2.1 Summary of the Test Programs

X2.1.1 A number of extensive research projects were undertaken for the development of this test protocol. These include:

X2.1.1.1 Water uptake measurements of specimens in Florida and in laboratory tests. This program lasted over 5 years. Water uptake was measured by weighing the specimens before and after the water events. This included measuring total natural water uptake and drying in Florida, as well as how these processes occurred in a variety of different laboratory cycles (2, 6, 7, 8).

X2.1.1.2 Outdoor measurements of temperature/time profile of various types and colors of specimens (7).

X2.1.1.3 Florida outdoor exposure tests of many different coating formulations (3).

X2.1.1.4 Laboratory exposure tests to determine the maximum irradiance that could be used without causing unnatural chemical changes (6).

X2.1.1.5 Laboratory exposure tests with a variety of optical filters to determine a Spectral Power Distribution that reproduces degradation observed in Florida (6).

X2.1.1.6 Laboratory exposure tests using many different wetting cycles and ways of introducing water (9).

X2.1.1.7 Laboratory tests using many different temperatures and humidities.

X2.1.1.8 Types of degradation effects measured in these tests include: gloss loss, cracking, color change, adhesion, delamination, photo-oxidation via photo-acoustic IR, and retention of UV absorber via microscope (9, 10).

X2.1.2 The following abbreviations are used in the Step descriptions:

X2.1.2.1 BP — black panel temperature

X2.1.2.2 CA — chamber air temperature

X2.1.2.3 RH — relative humidity

## **X2.2 Step 1:**

**240 min, Dark+Spray, CA 40°C, RH 95 %**

X2.2.1 The purpose of this step is to produce water uptake within the coating that is similar to the maximum uptake in a normal day outdoors in south Florida. This is close to full saturation, but not total saturation. Water uptake *more than* what is achieved in Step 1 did not produce significant changes in test results. However, water uptake *less* than what Step 1 achieves did fail to produce degradation of the types found in Florida.

X2.2.2 Measurements in Florida showed that water absorbed into the coating could exceed 5 % of the total coating volume. Different coating layers absorb different amounts of water. For instance, waterborne coatings or powder coatings might have higher water uptake than solvent borne coatings (7).

X2.2.3 Water uptake within the coating causes migration of materials within the coating layers. This migration can lead to chemical reactions that cause mechanical failures such as cracking, loss of intercoat adhesion, and delamination of a primer from the electrocoat. Water also carries low molecular weight materials out of the coating, for instance light stabilizers, surfactants, and acid catalysts. Loss of the stabilizers can cause increased gloss loss and chalking.

X2.2.4 Previous cycles historically used for automotive coatings did not achieve enough water uptake to match Florida exposure.

X2.2.5 For Step 1, a temperature of 40°C was chosen because outdoor uptake measurements showed significant reductions in the volume of water within the coating when temperatures rose above 40°C. This is because, in Florida, specimen temperatures above 40°C only occur when the sun is drying out the coating. A lower temperature was not chosen, because the ability of the coating to take up water at 40°C is maximized due to softening of the coating. For example at 25°C it might take twice as much wet time to produce the same water uptake as 40°C. Furthermore, 40°C does not have the possibility of adding unnatural stress caused by temperature alone.

X2.2.6 This step is dark (the lights are off) because almost all wetness in Florida occurs when there is no sunshine. The vast majority of wet time is caused by nighttime dew. Even

wetness caused by daytime rain also occurs primarily when the sun is obscured by clouds.

X2.2.7 A long wet time of 4 h was chosen, because at 40°C this amount of time is necessary to achieve a similar mass of water uptake as would occur in a typical Florida night. Outdoor data show that natural specimen wet temperature is lower in Florida, typically 20 to 25°C. But outdoor wet periods were also much longer, ranging for 8 to 16 h. So 4 h at 40°C produces similar water uptake to the much longer, but cooler, Florida wet periods (11).

X2.2.8 The RH is set at 95 %+ because this ensures that the specimens stay wet for the entire 4 h period.

## **X2.3 Step 2:**

**30 min, Light, 0.40 W/(m<sup>2</sup>·nm) irradiance, BP 50°C, CA 42°C, RH 50 %**

X2.3.1 The purpose of this step is to totally remove all of the water from within the coating layers. In a typical Florida day, the sun comes up and dries out the coating completely by mid morning.

X2.3.2 The irradiance is set at a relatively low level, 0.40 W/(m<sup>2</sup>·nm) because Florida data has shown that all the water was driven off from the coating before the sun ever got high enough in the sky to produce higher irradiances.

X2.3.3 The black panel temperature is set at 50°C because Florida data has shown that by the time the sun heats the specimen to 50°C almost all of the water has been removed from the coating.

X2.3.4 Unnatural effects can be produced if the test does not remove all of the water before the start of the high-temperature, high-irradiance step. For instance excessive cracking and micro cracking can be produced if water inside the coating is heated up too quickly.

X2.3.5 A time of 30 min was chosen because data has shown that 30 min at 50°C is the time required to take the water content to near zero.

X2.3.6 The RH of 50 % was chosen because a higher humidity will require too long a time to remove all of the water. Perhaps a lower humidity could have been chosen. But 50 % is a realistic outdoor humidity that works for this step. The important thing is that the RH is in fact controlled because different humidities will cause different rates of drying.

## **X2.4 Step 3:**

**270 min, Light, 0.80 W/(m<sup>2</sup>·nm) irradiance, BP 70°C, CA 50°C, RH 50 %**

X2.4.1 This step simulates the effects of bright sunlight on the coatings. Most of this degradation is surface effects, such as photo-oxidation, gloss loss, color change, and micro cracking. Most previous tests have concentrated on this type of exposure and not given enough emphasis to other types of exposure.

X2.4.2 The irradiance is set at somewhat higher than the maximum irradiance seen in Florida with noon midsummer sunlight. Furthermore, most Florida sunlight exposure occurs

at much lower irradiances than noon midsummer sunlight. So this irradiance can be expected to produce significant acceleration.

X2.4.3 Data has shown that this higher irradiance does not change the fundamental chemical mechanisms seen in Florida exposure of automotive coatings. In contrast, IR analysis of exposures at 1.1 W/(m<sup>2</sup>·nm), showed that such a high irradiance does indeed change the fundamental chemical processes in unnatural ways (5).

X2.4.4 The black panel temperature is set at 70°C because this approximates the maximum specimen temperature averaged across the color palette. In other words, a white specimen will rarely get above 55°C, while a black specimen may reach 80°C. The black panel temperature of 70°C is a reasonable compromise. Note that these maximum temperatures only occur around noon in the summertime. In Florida specimen temperature is less than 70°C during most of their time of sunlight exposure.

#### **X2.5 Step 4:**

**30 min, Light, 0.40 W/(m<sup>2</sup>·nm) irradiance, BP 50°C, CA 42°C, RH 50 %**

X2.5.1 This step is intended as a transitional “relaxation” step between the hot, high-irradiance “daytime” step and the dark, cool, wet “night time” step. This step gradually reduces thermal stresses within the coating, similar to what occurs as the sun gets lower in the sky during the evening (12).

X2.5.2 The relatively low set points for irradiance and temperature are typical of what has been measured in late afternoon and early evening in Florida.

X2.5.3 Unnatural effects can be produced if the test does not cool down the specimens before water is introduced. For instance excessive cracking and micro cracking can be produced if cold water is sprayed onto a hot specimen.

#### **X2.6 Step 5:**

**150 min, Dark+Spray, CA 40°C, RH 95 %**

X2.6.1 The purpose of this step is to produce significant water uptake within the coating, but at somewhat less than the maximum uptake observed. The data has shown that the maximum water uptake does not occur every day in Florida. This step is intended to simulate those days of less than maximum uptake.

X2.6.2 Note that Step 6 has the same conditions as Step 5, but for only 30 min. Combined, Steps 5 and 6 give a total of 180 min of water uptake conditions. However, Step 6 is also part of a repeating subcycle as described below.

X2.6.3 The temperatures and humidities in Step 5 are the same as in Step 1 for the same reasons.

#### **X2.7 Steps 6, 7, 8, 9 (Overview)**

X2.7.1 These steps are repeated four times in a subcycle. This subcycle incorporates relatively rapid changes in conditions in order to test the coating’s mechanical and viscoelastic properties as they relate to weathering. These properties include relative modulus and strain values. For example, thicker coatings are more susceptible to cracking caused by thermal cycling or wet/dry cycling. Also this mechanical stress cycling can cause delamination of coating layers.

#### **X2.8 Step 6:**

**30 min, Dark+Spray, CA 40°C, RH 95 %**

X2.8.1 This step is the same conditions as Step 1 and Step 5 except for shorter time. This is intended to simulate a very short time water event, such as a night where little condensation occurs, or a very short rain event. A short, 30 min, wet step will only produce water uptake in the surface layers of the coating. The water does not have enough time to permeate into the lower layers.

#### **X2.9 Step 7:**

**20 min, Light, 0.40 W/(m<sup>2</sup>·nm) irradiance, BP 50°C, CA 42°C, RH 50 %**

X2.9.1 This step is the same conditions as Step 2 and Step 4 except for a shorter time. The purpose of this step is to remove the water from the coating at a controlled rate. Because the preceding wet step was shorter, this drying step can be shorter.

#### **X2.10 Step 8:**

**120 min, Light, 0.80 W/(m<sup>2</sup>·nm) irradiance, BP 70°C, CA 50°C, RH 50 %**

X2.10.1 These are the same conditions as Step 3 but for a shorter time. The purpose of this step is to heat up the specimen to create mechanical stresses. The time is kept to a relatively short 120 min so that the stresses cycle rapidly.

X2.10.2 The high irradiance also contributes to the accumulated photochemical degradation, but that is a secondary purpose of this step.

#### **X2.11 Step 9:**

**10 min, Dark, CA 40°C, RH 50 %**

X2.11.1 This step is intended as a total relaxation from all stresses. There are frequently times during outdoor exposures when there are no stresses from sunlight, temperature, or water. If the coating is never allowed a relaxation period, it is thought that unnatural effects might occur such as excessive cracking.

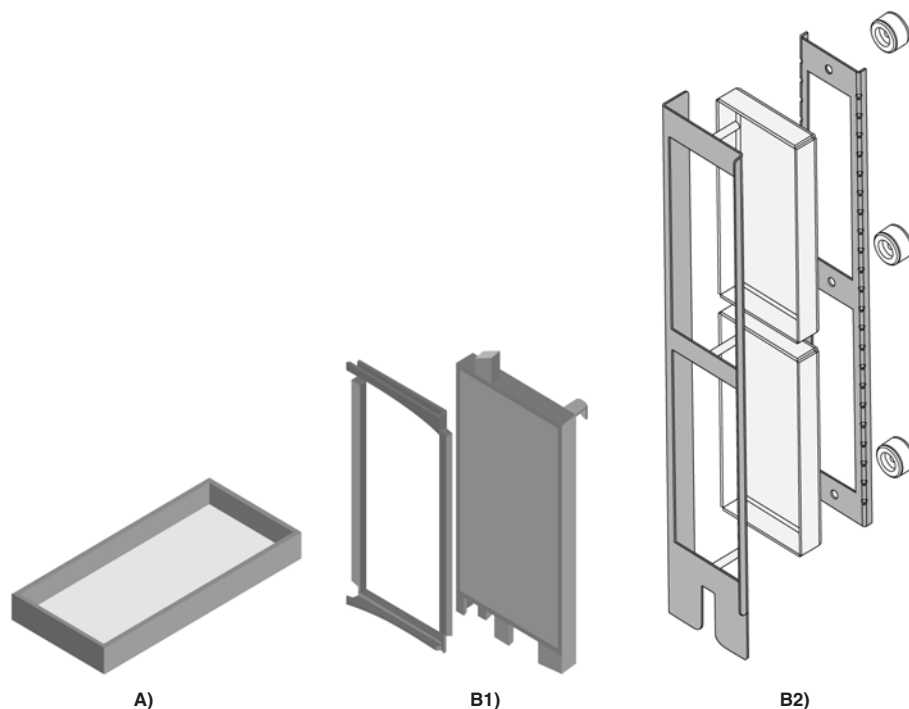
#### **X2.12 Step 10:**

**Repeat Steps 6–9 an additional 3 times**

X2.12.1 Note that Steps 6 through 9 are repeated a total of four times.



**X3. EXAMPLES OF SPECIMEN HOLDER DESIGNS FOR FLAT ARRAY (A) AND ROTATING RACK (B1, B2) APPARATUSES (Fig. X3.1) THAT FULFILL THE REQUIREMENTS OF THIS STANDARD (SEE SECTION A3.1)**



**FIG. X3.1 Specimen Holder Designs**

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