Designation: E 1038 – 98 (Reapproved 2004)

Standard Test Method for Determining Resistance of Photovoltaic Modules to Hail by Impact with Propelled Ice Balls[1]

This standard is issued under the fixed designation E 1038; 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 provides a procedure for determining the ability of photovoltaic modules to withstand impact forces of falling hail. Propelled ice balls are used to simulate falling hailstones.

1.2 This test method defines test specimens and methods for mounting specimens, specifies impact locations on each test specimen, provides an equation for determining the velocity of any size ice ball, provides a method for impacting the test specimens with ice balls, provides a method for determining changes in electrical performance, and specifies parameters that must be recorded and reported.

1.3 This test method does not establish pass or fail levels. The determination of acceptable or unacceptable levels of ice ball impact resistance is beyond the scope of this test method.

1.4 The size of the ice ball to be used in conducting this test is not specified. This test method can be used with various sizes of ice balls.

1.5 This test method may be applied to concentrator and nonconcentrator modules.

1.6 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.7 *This standard does not purport to address all of the safety problems, 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.* For specific precautionary statements, refer to 5.1, Section 6, Note 8, and Note 9.

2. Referenced Documents

2.1 *ASTM Standards:*

E 772 Terminology Relating to Solar Energy Conversion[2]

E 822 Practice for Determining Resistance of Solar Collector Covers to Hail by Impact with Propelled Ice Balls[2]

E 1036 Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells[2]

E 1328 Terminology Relating to Photovoltaic Solar Energy Conversion[2]

E 1462 Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules[2]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, see Terminology E 772 and Terminology E 1328.

3.2 *Symbols*—The following symbols are used in this test method.

m = ice ball mass, g,
d = ice ball diameter, mm, and
r = ice ball radius, mm.

3.2.1 *Velocity*:

V_t = ice ball terminal, m s^{-1},
V_w = wind, m s^{-1}, and
V_r = ice ball resultant, m s^{-1}.

4. Significance and Use

4.1 In many geographic areas, there is concern about the effect of falling hail upon photovoltaic modules. This test method may be used to determine the ability of photovoltaic modules to withstand the impact forces of hailstones. In this test method, the ability of a photovoltaic module to withstand hail impact is related to its tested ability to withstand impact from ice balls. The effects of impact may be either physical or electrical degradation of the module.

4.2 This test method describes a standard procedure for mounting the test specimen, conducting the impact test, and reporting the effects.

4.2.1 The procedures for mounting the test specimen are provided to assure that modules are tested in a configuration that relates to their use in a photovoltaic array.

4.2.2 Six or more impact locations are chosen to represent vulnerable sites on modules and general locations are listed in Table 1. Only a single impact is specified at each of the impact locations.

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[1] This test method is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal, and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Systems.

Current edition approved June 10, 1998. Published December 1998. Originally published as E 1038 – 85. Last previous edition E 1038 – 93.

[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.

TABLE 1 Candidate Locations and Suggested Order for Impact Points

Location number	Description
1	Centers of cells
2	Edges of cells, especially near electrical contacts
3	Points of minimum spacing between cells
4	Points of maximum distance from points of support in 6 Corners and edges of the module
5	Points of support for any superstrate material
6	Back of module, if exposed in stowed orientation
7	Electrical terminals and leads
8	Centers of lenses approximately 50 mm from lens support points
9	

4.2.3 Resultant velocity is used to simulate the velocity that may be reached by hail accompanied by wind. The resultant velocity used in this test method is determined by vector addition of horizontal velocity to the vertical terminal velocity.

4.2.4 Ice balls are used in this test method to simulate hailstones. Hailstones are variable in properties such as shape, density, and frangibility (for fracture characteristics, see Ref (10) in Practice E 822). These properties affect factors such as the duration and magnitude of the impulsive force acting on the module and the area over which the impulse is distributed. Ice balls (with a density, frangibility, and terminal velocity near the range of hailstones) are the nearest hailstone approximation known at this time. Ice balls generally are harder and denser than hailstones; therefore, an ice ball simulates the worst case hailstone. Perhaps the major difference between ice balls and hailstones is that hailstones are more variable than ice balls. Ice balls can be uniformly and repeatedly manufactured to assure a projectile with known properties.

4.3 Data generated using this test method may be used for the following: (*1*) to evaluate impact resistance of a module, (*2*) to compare the impact resistance of several modules, (*3*) to provide a common basis for selection of modules for use in various geographic areas, or (*4*) to evaluate changes in impact resistance of modules due to other environmental factors, such as weathering.

4.3.1 This test method requires analysis of visual effects, as well as electrical measurements. Visual effects are generally more sensitive than the electrical measurements; therefore, the absolute values for voltage and current are not critical, but repeatable conditions for before and after tests are required for determining electrical changes.

4.3.2 A range of observable effects may be produced by impacting various types of photovoltaic modules. Physical effects on modules may vary from no effect to penetration by the ice ball. Some physical changes in the module may be visible when there is no apparent electrical degradation of the module.

4.3.3 Electrical changes may vary from no effect to no output. All effects of the impacts must be described in the report so that an estimate of their significance can be made.

4.4 This test method does not specify the size or velocity of ice balls or maximum number of impacts to be used in making the test. These determinations will be based on frequency and severity of expected hail occurrences and the intent of the testing.

4.4.1 If the testing is being performed to evaluate impact resistance of a single module, or several modules, it may be desirable to repeat the test using several sizes and velocities of ice balls. In this manner, the different effects of various sizes and velocities of ice balls may be determined. However, no point shall be impacted more than once (see 7.10).

4.4.2 The size and frequency of hail varies significantly among various geographic areas. If testing is being performed to evaluate modules intended for use in a specific geographic area, the ice ball size should correspond to the level of hail impact resistance required for that area. Information on hail size and frequency can be found in Appendix X1 of Practice E 822 and footnotes 3 and 4 of this test method, or may be available from local historical weather records.

4.4.3 When testing modules that are designed to be in a stowed position during hail storms, additional impact locations should be chosen accordingly.

4.5 The hail impact resistance of modules may change as the materials are exposed to various environmental factors. This test method may be used to evaluate degradation by comparison of hail impact resistance data measured before and after exposure to other such environmental factors.

5. Apparatus

5.1 *Launcher*, capable of propelling a selected ice ball at the specified velocity within ±5 %. The aiming accuracy of the launcher must be sufficient for the ice ball to strike the specified impact area, or the surrounding area must be masked for protection from inadvertent impacts.

NOTE 1—Launchers that have proven suitable utilize a compressed air supply, an accumulator tank, a large diameter quick-opening valve, and interchangeable barrels to accommodate different sizes of ice balls[3,4] (see Ref (14) of Practice E 822). Another launcher that has been used is a table-mounted slingshot with an adjustable hand rest.

5.2 *Velocity Meter*, for measuring ice ball velocity to within ±2 %.

5.3 *Test Base*—A rigid mount for supporting the test module in a fashion that simulates actual mounting applications.

5.4 *Molds*, for casting spherical ice balls of appropriate diameter.

NOTE 2—Molds made from silicone rubber or expanded polystyrene have been found suitable.

5.5 *Freezer*, for making ice balls in the molds, controlled at − 10 ± 5°C.

5.6 *Storage Container*—An ice chest or an ice water/salt mixture and a bag for the ice balls capable of maintaining temperature of − 4 ± 2°C.

[3] Moore, D., and Wilson, A., "Photovoltaic Solar Panel Resistance to Simulated Hail," *Low-Cost Solar Array Project Report 5101-62*, Jet Propulsion Laboratory, Pasadena, CA, 1978. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161-0001.

[4] Jenkins, D. R., and Mathey, R. G., "Hail Impact Testing Procedure for Solar Covers," NBSIR 82-2487, National Bureau of Standards, April 1982. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161-0001.

5.7 *Balance*, for determining ice ball mass to within ± 1 %.

5.8 *Ring Gages or Equivalent*, for determining ice ball size.

6. Hazards

6.1 The operation of the equipment described in Section 5 may expose personnel to risk of injury from propelled or rebounded ice balls, fragments of the broken test specimen, and from the noise that may develop. Eye and ear protection shall be considered as minimum protection for the operator.

7. Procedure

7.1 Determine the ice ball size to be used in the test.

NOTE 3—The size of the ice balls shall be specified in 6.35-mm (¼-in.) increments by the sponsor of the test or the test director.

7.2 Using the ice mold(s), make sufficient quantities of ice balls of the prescribed size(s). Examine for cracks, size, and weight. An acceptable ball shall meet the following criteria:

7.2.1 *Cracks*—No cracks visible to the unaided eye.

7.2.2 *Size*—Within ±5 % of specified diameter, and

7.2.3 *Mass*—Within ±5 % of nominal value listed.

d, mm (in.)	*m*, g
12.7 (½)	1.0
19.1 (¾)	3.3
25.4 (1)	7.9
31.8 (1¼)	15.4
38.1 (1½)	26.6
44.5 (1¾)	42.3
50.8 (2)	63.2
57.2 (2¼)	89.9
63.5 (2½)	123

$m = 0.00385\ r^3$.

7.3 Calculate the resultant velocity corresponding to the ice ball diameter and selected wind speed. The resultant velocity shall be determined using the following equation:

$$V_r = \sqrt{V_t^2 + V_w{}^2} \tag{1}$$

where:

$$V_t = 4.44\sqrt{d} \tag{2}$$

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7.3.1 The wind speed is selected from the following table by the sponsor of the test or the test director.

m·s⁻¹ (mile·h⁻¹)
0 (0)
13 (30)
20 (45)
27 (60)

NOTE 4—Considerations for appropriate wind speeds may be found in footnote 4.

7.4 *Electrical Tests*:

7.4.1 Perform an insulation current leakage test on the test module according to 7.1 of Test Methods E 1462.

7.4.2 Measure the open-circuit voltage and short-circuit current of the module. As acceptable procedure is given in Methods E 1036.

NOTE 5—Because damage to a module that results from ice ball impact is usually catastrophic, it is only necessary to determine if the V_{oc} and I_{sc} survive the impact test. Thus, a simple measurement of V_{oc} and I_{sc} using a voltmeter and an ammeter while the module is illuminated is permissible.

7.5 Select a minimum of six target impact points identified in Table 1.

7.6 Document visual features in the impact areas that may be affected by the ice balls. Photographs may be used.

7.7 Mount the test module on a suitable test base to simulate an actual installation of the module. The specified impact points shall not be obstructed by the mounting fixtures.

7.8 The test module temperature shall be stable and the ambient temperature shall be 20 ± 10°C.

7.9 Position the module to assure that the path of the propelled ice ball at impact will be perpendicular (90 ± 5°) to the surface at the target point.

NOTE 6—The apparatus may be designed so that the path of the ice ball is at any angle, for example, horizontal or vertical, as long as the other requirements of the test are met.

7.10 Aim the launcher at a target impact point that has not previously been impacted. Each point shall be impacted one time only.

7.11 Position the velocity meter such that the ice ball velocity will be measured between the launcher and the test specimen. The ice ball should leave the velocity meter not more than 1.0 m (3.1 ft) in front of the impact location. Prepare the velocity meter for the test.

NOTE 7—Testing of the apparatus may be done by impacting ice balls on a simulated target placed in front of the module.

NOTE 8—A shield may be placed around the impact point for protection.

7.12 Set the launcher controls to assure that the ball will be propelled at the velocity determined in 7.3.

7.13 Remove an ice ball from the storage container.

7.14 Place the ice ball in the launcher.

7.15 Launch the ice ball. Measure and record the velocity of the ice ball. Ice balls shall impact the test specimen within 60 s of removal from the storage container.

NOTE 9—**Caution:** Personnel protective equipment may be required during this step (see 6.1).

7.16 Mark the ice ball impact location.

7.17 Record all visual effects of the impact.

7.18 Repeat 7.8-7.16, until one of the following occurs:

7.18.1 All selected target points have been impacted, or

7.18.2 Severe damage of the module occurs.

7.19 At the completion of the test, repeat the electrical tests in 7.4.

8. Report

8.1 Report, as a minimum, the following information:

8.1.1 Module manufacturer and type,

8.1.2 Module description that includes the following items:

8.1.2.1 Major dimensions,

8.1.2.2 Substrate material and thickness,

8.1.2.3 Superstrate material and thickness, and

8.1.2.4 Cell material,

8.1.3 A line drawing or photograph of the module with impact sites marked,

8.1.4 A line drawing or photograph of the module mounting,

8.1.5 Description of physical degradation, if any, 8.1.6 Changes between pre and post electrical test results, if any,

8.1.7 Size, mass, and velocity of ice balls used,

8.1.8 Temperature of module during impacts,

8.1.9 A brief description of device used to propel the ice balls and the device used to measure its velocity, and

8.1.10 Any deviation from this test method.

9. Precision and Bias

9.1 The ice-ball impact testing described in this test method does not produce numeric results that would be subject to ASTM procedures for evaluating the precision and bias of this test method. However, the precision and bias of the electrical performance measurements, when performed in accordance with Methods E 1036, are subject to the provisions of that document.

10. Keywords

10.1 hail resistance; ice ball impact testing; modules; photovoltaics; solar energy