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INTERNATIONAL STANDARD

colour inside

Printed electronics –
Part 501-1: Quality assessment – Failure modes and mechanical testing – Flexible or bendable primary or secondary cells

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PRINTED ELECTRONICS –

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FOREWORD

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International Standard IEC 62899-501-1 has been prepared by IEC technical committee 119: Printed Electronics.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
119/241/FDIS	119/245/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62899 series, published under the general title *Printed electronics*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Due to the trend towards a globalised, technological and connected society there is a rising demand for a new breed of technologies enabling low-priced, flexible and new-concept products. Some conventional technologies (including silicon-based microelectronics) have reached their limits due to their high fabrication costs and environmental impact. Armed with new printing technologies (e.g., ink jet) and innovative materials, printed electronics have recently emerged as a promising, environmentally friendly route toward producing electronic, display or energy storage articles at low cost, enabling new creative technologies such as flexible electronics. Currently, this technology is beginning to be applied for the industrial production of items such as photovoltaic devices, signage, RFID, batteries, lighting devices, some parts of display devices, where cost, flexibility and recycling are very critical issues. For successful industrialization of this technology, reliability and repeatability in equipment and process should be provided under global standardization.

In the interests of improving communication, printed electronics terminology should be identical to, or analogous with, standardised terminology approved by technical committees in the following areas (since one or more of these will be commonly used concurrently with printed electronics):

- TC 21: Secondary cells and batteries
- SC 21A: Secondary cells and batteries containing alkaline or other non-acid electrolytes
- TC 35: Primary cells and batteries
- TC 113: Nanotechnology for electrotechnical products and systems

PRINTED ELECTRONICS –

Part 501-1: Quality assessment – Failure modes and mechanical testing – Flexible or bendable primary or secondary cells

1 Scope

This part of IEC 62899 specifies failure modes and mechanical stress test methods for the determination of reliability characteristics of bendable or flexible printed primary cells and secondary cells and batteries as defined in IEC 60050-482:2004, 482-01-01, IEC 60050-482:2004, 482-01-02, IEC 60050-482:2004, 482-01-03, IEC 60050-482:2004, 482-01-04 and IEC 60050-482:2004, 482-01-05, respectively.

Important parameters and specifications for primary cells are mentioned in IEC 60086-1 and IEC 60086-2. IEC 61960-3, as well as IEC 61951-1 and IEC 61951-2 define performance tests, designations, markings, dimensions and other requirements for secondary single cells and batteries. IEC 62133-1 and IEC 62133-2 address general safety requirements of secondary cells and batteries.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-482, *International Electrotechnical Vocabulary (IEV) – Part 482: Primary and secondary cells and batteries* (available at www.electropedia.org)

ISO/IEC 10373-1*, Identification cards – Test methods – Part 1: General characteristics*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-482 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
cell
basic functional unit, consisting of an assembly of electrode terminals, electrolyte, container, terminals and usually separators, that is a source of electric energy obtained by direct conversion of chemical energy

Note 1 to entry: See primary cell and secondary cell.

3.2
primary cell
cell which is not designed to be electrically recharged

3.3
secondary cell
cell which is designed to be electrically recharged

Note 1 to entry: The recharge is accomplished by way of a reversible chemical reaction.

3.4
battery
one or more cells fitted with devices necessary for use, for example case, terminals, marking and protective devices

3.5
electrolyte
liquid or solid substance containing mobile ions which render it ionically conductive

Note 1 to entry: The electrolyte may be liquid, solid or a gel.

[SOURCE: IEC 60050-482:2004, 482-02-29]

3.6
nominal value
value of a quantity used to designate and identify a component, device, equipment, or system

Note 1 to entry: The nominal value is generally a rounded value.

[SOURCE: IEC 60050-151:2001, 151-16-09]

3.7
capacity (for cells or batteries)
electric charge which a cell or battery can deliver under specified discharge conditions

Note 1 to entry: The SI unit for electric charge, or quantity of electricity, is the coulomb (1 C = 1 A·s) but in practice, capacity is usually expressed in ampere hours (A·h).

[SOURCE: IEC 60050-482:2004, 482-03-14]

3.8
rated capacity
<cells or batteries> capacity value of a cell or battery determined under specified conditions and declared by the manufacturer

Note 1 to entry: The rated capacity is the quantity of electricity C_5 in A·h (ampere-hours) declared by the manufacturer which a single cell can deliver during a 5-h period, when charged, stored and discharged.

[SOURCE: IEC 60050-482:2004, 482-03-15, modified – a note has been added.]

3.9
discharge (for cells or batteries)
operation by which a battery delivers, to an external electric circuit and under specified conditions, electric energy produced in the cells

[SOURCE: IEC 60050-482:2004, 482-03-23]

3.10
nominal voltage
suitable approximate value of the voltage used to designate or identify a cell, a battery or an electrochemical system

[SOURCE: IEC 60050-482:2004, 482-03-31]

3.11
open-circuit voltage
OCV
voltage of a cell or battery when the discharge current is zero

[SOURCE: IEC 60050-482:2004, 482-03-32]

3.12
closed circuit voltage
CCV
voltage of a cell or battery when a charge or a discharge is applied

Note 1 to entry: More definitions and references on discharge parameters are provided in IEC 60086 (all parts).

4 Characteristics

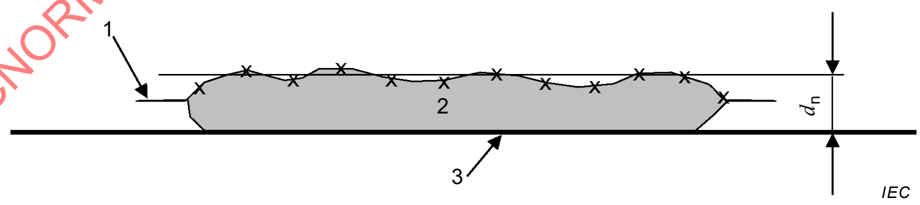
4.1 Geometrical cell properties

4.1.1 General specifications for measurement

If not specified otherwise, all measurements shall be conducted at 20 °C ± 5 °C. If not specified otherwise, at least 5 cells or batteries of one lot should be tested. The cell or battery should be stored for at least 24 h at 20 °C ± 5 °C before thickness measurement.

4.1.2 Measuring method for cell thickness determination

The cell or battery thickness d_{c} may vary locally over its lateral dimension as a result of inhomogeneities during charge collector coating, electrolyte application, or cell assembly. Thus, its nominal thickness value $d_{\mathrm{c},n}$ is regarded as the arithmetic mean value $d_{\mathrm{c},n} = \frac{1}{m}\sum_{a=5}^{m} d_a$ of m local thickness values d_a, measured without contact (for example optically) or mechanically (for example with a scanning tip, with negligible influence on cell thickness during measurement) on a sufficient number of different points (for example an x-/y-raster) on the flat package surface while the cell is stored with its backside on a flat, rigid and stiff support (Figure 1). The number of measurement points n shall be at least 5. The measurement points are homogeneously spread over the cell and are neither lying on the lamination edge nor on the contacts, but only on the electrolyte-containing part of the cell. Points on inward-lying contacts or other structures are also to be avoided.



Key

1 laminated package edge

2 cell or battery package (cross section)

3 flat, rigid and stiff support

Figure 1 – Schematic description of battery thickness measurement

The “x” marks represent equally-spaced measurement points. The acquisition of at least 5 measurement points is recommended. On rectangular cells, these points can be located at the package corners and at its centre. From this analysis, maximum and minimum thickness values may be derived and specified.

NOTE Cell thickness change due to the influence of measurement is negligible when the thickness change is less than 5 % of the cell thickness.

4.1.3 Measuring method for cell volume and cell volume change calculation

4.1.3.1 General remarks

Cell volume may change during charge and discharge. For cell volume determination, the cell can be measured by optical scanning (OS), by X-ray computer tomography (CT), by dipping into a fluid of known volume or by other methods, as defined by the manufacturer.

4.1.3.2 Optical measurement

The OS measurement employs a 2D scan of the cell surface referenced to the flat and rigid supporting surface, either by using a 2D (x,y) oscillating micro- or galvo-scanner or by using a 1D (x) oscillating line scanner with y-moving cell support. In both cases, the topography of the cell surface is measured by triangulation. The disadvantage of this setup is that only visible, open structures can be measured and some error can occur due to hidden air volumes below the cell. This method is both suited for cell volume and cell volume change measurement.

4.1.3.3 CT measurement

The CT measurement employs an X-ray source and a rotating and upwards and downwards (z-)moving cell holder. During cell rotation and perpendicular movement, the X-rays are partially absorbed by the cell depending on local thickness and material density variations. A detector monitors the absorbed X-rays. The raw data it provides is further processed by the CT computer system. The system then provides a 3D model of the cell, which allows for calculating the cell volume with high precision. This method is suited for static volume measurement.

4.1.3.4 Cell dipping

The cell with waterproof isolated electrode terminals is dipped into water or another suitable fluid located in a measuring glass with a sufficiently fine graduation. The volume change is measured by reading the liquid level change on the graduation. This method is only suited for water- or fluid-resistant cell packages.

4.1.3.5 Other methods

Other methods suitable for cell volume analysis can be defined by the manufacturer.

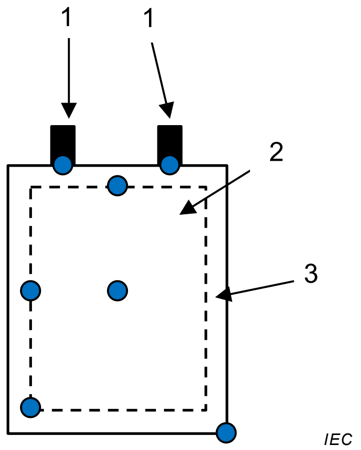
4.2 Mechanical characteristics

4.2.1 General remarks

If not specified otherwise, all measurements shall be conducted at 20 °C ± 5 °C. If not specified otherwise, at least 5 cells or batteries of one lot should be tested.

4.2.2 Mechanical stability (of battery package and contacts)

The cell or battery should resist damage, resulting in battery failure (see Clause 5), to its surface and to any components contained in it and should remain intact during normal use, storage and handling. Each contact surface and contact area (the entire galvanic surface) shall not be damaged by a working pressure equivalent to a steel ball of 1 mm diameter applying a force of 1,5 N. Instead of steel, another suitable ball material can be used. This material should be hard enough and should not be influenced by the measurement. The test points are shown in Figure 2. Additional points can be defined by the manufacturer.



Key

1 electrode terminals (leads, contacts)

2 cell package

3 lamination frame

Figure 2 – Test points for testing the mechanical strength of cell or battery package with a steel ball tip

4.2.3 Bending test

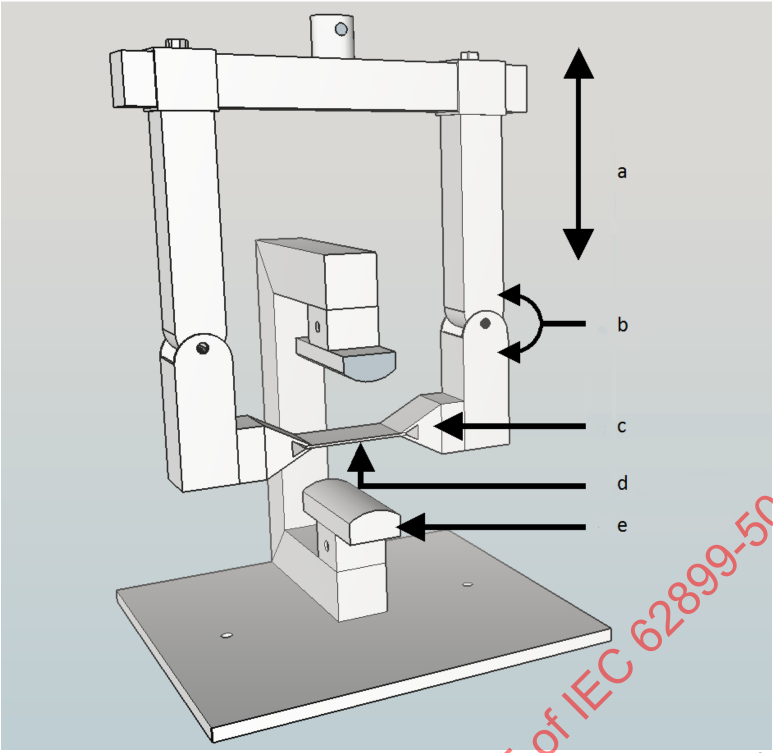
4.2.3.1 General remarks

Bending properties shall be tested by exposing the cell to dynamic bending stress. When subjected to a total of 1 000 bending cycles, the cell shall still work according to the specified performance values and shall not show any package damage, cracked part, lose contact or more than 5 % loss in nominal capacity C. When testing secondary cells more than once, i.e. after more than one loading cycle, with 1 000 cycles or a number of cycles specified by the manufacturer, the nominal loss in capacity C should not exceed 5 % or an amount specified by the manufacturer, compared to the non-cycled cell in the same state.

4.2.3.2 Description of the bending apparatus

The dynamic bending test should be conducted using a test fixture where both edges of the cell or battery package are clamped and the electrical cell parameters (voltage U, capacity C) are measured while the battery is bent. The cell shall be tested while clamped horizontally. A testing setup is shown schematically in Figure 3.

Due to potential disadvantageous relations between the bending velocity and cell-intrinsic properties, for example electrolyte thixotropy, a suitable maximum bending velocity should be defined by the manufacturer. A typical bending velocity range of 20 mm/s to 50 mm/s should be considered as a baseline value.



Key

a indicates the upwards and downwards movement directions

b right hinge

c right parallel vice for cell or battery clamping

d flexible cell or battery

e lower bending radius, which can be varied

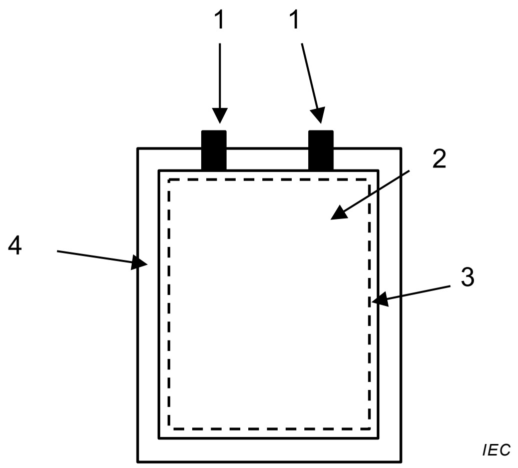
Figure 3 – Measurement setup for mechanical testing of flexible cells or batteries

The cell or battery is clamped horizontally and is bent to a defined radius while moving to the upper or lower radius. One displacement up followed by one displacement down or vice versa represents one bending cycle. Battery stretching has to be avoided by limiting the moving distance.

During the bending tests, OCV, CCV and discharge according to defined specifications should be measured with a suitable setup. For primary cells, only one discharge curve can be measured. For a high number of bending cycles, this measurement approaches the measurement of the cell or battery discharge curve or the battery capacitance, respectively. For correct measurement, a small discharge current I corresponding to 5 % or a value between 2 % and 10 % of the specified maximum electrical power rating of the cell (as defined by the manufacturer) shall be used. This can either be achieved by applying an appropriately dimensioned electrical load (resistor), or by using a suitable battery tester. If possible, only the laminated package edges not covered or penetrated by the electrodes should be clamped. Package regions containing electrolytes shall not be clamped.

4.2.3.3 Clamping cells with small package lamination edges

Some flexible cells or batteries may contain a narrow lamination frame where clamping for mechanical testing will not be possible. To avoid clamping the electrolyte containing package regions, the cell should be fixed on a bendable substrate with a suitable glue or strip as shown in Figure 4. Both glue and strip should not influence the measurement.



Key

1 electrode terminals (leads, contacts)

2 cell package

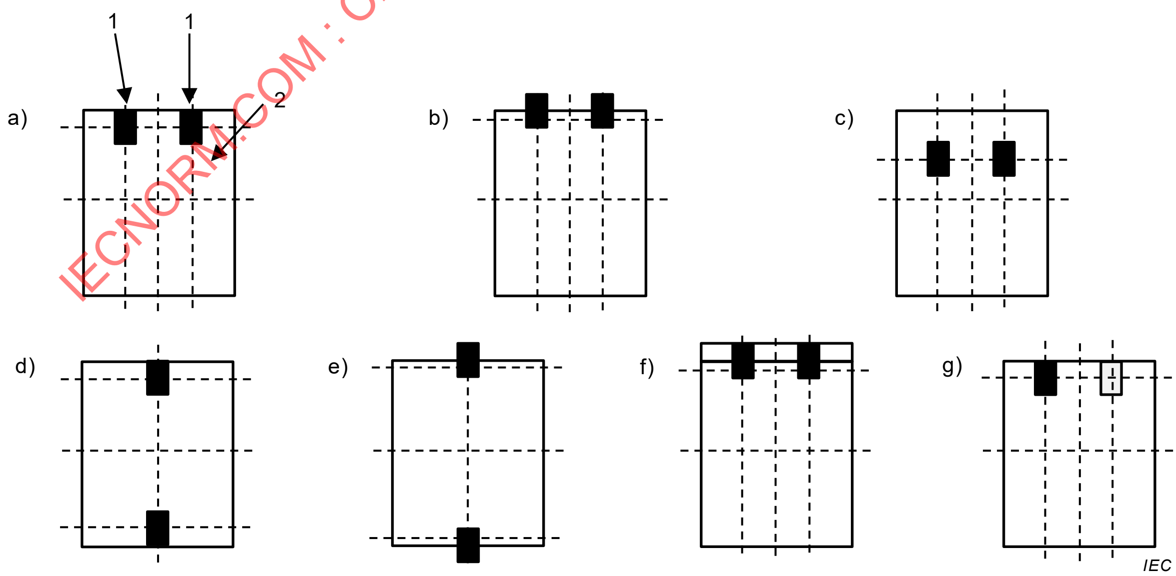
3 non-clampable lamination frame right parallel vice for cell or battery clamping

4 bendable substrate as cell carrier

Figure 4 – Flexible substrate carrier for cell or battery packages with small and non-clampable lamination frame

For mechanical measurements, the battery should be in a charged state so that parallel measurement of the discharge curve or other electrical battery parameters will be possible. Safety regulations have to be followed and considered.

For different purposes and depending on the cell geometry and layout, different bending directions will be defined. The bending axes (dashed lines in Figure 5) refer to the package symmetry and design added by the axes to test electrode connections into the package. The images a) to g) in Figure 5 show some design examples. If necessary for clamping, an insulating material (e.g. a plastic strip) may be used to avoid electrical shorts.



Key

1 electrode terminals (leads, contacts)

2 cell package

Figure 5 – Possible cell or battery designs with bending axes (dashed)

The description of the various designs is as follows (see Figure 5 for reference):

a) Electrode terminals one-sided, completely supported by the package, and touching the package edge.
b) Electrode terminals one-sided, and exceeding the package edge.
c) Electrode terminals located in the package area, and not touching the package edges.
d) Electrode terminals located at opposite package edges, and completely supported by the package.
e) Electrode terminals located at opposite package edges, and exceeding package edges.
f) Electrode terminals one-sided, and supported by backside package foil.
g) Electrode terminals one-sided, completely supported by the package, with one electrode on the front side, one electrode on the backside, and touching the package edges.

If clamping for an axis is not possible due to a small laminate edge or for other reasons, the cell can be mounted on a flexible carrier with greater lateral dimensions as described in Figure 4.

If cell design deviates from the above examples a) to g), the manufacturer should define the bending axes. If there are other reasons why these bending axes cannot be applied (e.g. if there are rigid parts in or on the flexible package), the manufacturer should define suitable bending axes. For reasons of symmetry and/or if recommended by the manufacturer, bending around some axes may be omitted, varied or added.

Three bending classes are defined for different purposes:

Class A: one bending test for the simulation of battery assembly;

Class B: 1 000 bending cycles for the simulation of battery usage;

Class C: bending cycles defined by manufacturer.

The manufacturer shall specify which class shall be applied.

The tested value of the bending radius r_b is divided into seven classes (beginning from higher values):

Class 1: down to 100 mm;

Class 2: down to 50 mm;

Class 3: down to 25 mm;

Class 4: down to 10 mm;

Class 5: down to 5 mm;

Class 6: down to $2d_n$;

Class 7: r_b defined by the manufacturer.

The bending radius is application dependent and should be specified by the manufacturer. The minimum bending radius should not be lower than $2d_n$.

4.2.4 Torsion properties

When subjected to a total of 1 000 torsion cycles or a cycle number defined by the manufacturer as described in ISO/IEC 10373-1, the cell or battery shall still function and shall not show any cracked part.

5 Failure criteria

5.1 Mechanical package damage and heat generation

When the package of a flexible/bendable cell or battery is penetrated by a pointed or sharp object (e.g. a nail or a knife) internal shorts and severe heat generation may occur. Depending on application, different maximum tolerable temperature classes are defined:

Class 1 (max. 40 °C): package has direct contact to human or animal skin;

Class 2 (max. 60 °C): package and human or animal skins are separated by cloth;

Class 3 (max. 100 °C): package is used in normal, not specially protected environment;

Class 4 (max. 140 °C): package may destroy itself and electrolyte may pollute the environment;

Class 5: defined by the manufacturer.

Cell or battery temperature shall be measured either by directly attaching a temperature sensor (thermocouple) to the cell or battery in close vicinity to the damaged area, or by monitoring cell or battery temperature with a radiative/IR sensor. The maximum temperature measured over the course of the test shall be recorded. For testing procedures, see IEC 62133 (all parts).

5.2 Failure states

A flexible and/or bendable cell or battery is considered to be in failure state when

1) its package foil is obviously and unintentionally perforated or delaminated;
2) its package is leaking electrolyte (liquid, solid or gel);
3) one or both of its electrical contacts are damaged, broken, or missing, so that a proper electrical contacting is not possible;
4) there is an electrical short between the contacts or between the conducting package parts and one or both of its contacts;
5) its nominal capacity is less than 70 % of its specified value. Secondary cells are in failure when more than 70 % nominal capacity cannot be reached during the specified recharging process;

   NOTE Alternatively and when demanded by application the capacity limit can be increased to 80 %.

6) there is ignition of electrolyte after cell damage;
7) smoke or fumes are emitted as a consequence of cell damage;
8) there is unspecified cell or battery package deformation;
9) there is unspecified cell or battery package expansion;
10) there is a sudden temperature rise, for example caused by an internal short, of the cell package so that either human skin or the cell surrounding can be harmed or the environment can be ignited or damaged (refer to 5.1).

6 Storage conditions

Cell storage conditions, especially storage temperature or temperature ranges and storage time, shall be such as to ensure that the maximum storage time defined by the manufacturer will maintain cell function and properties and that there are no cell failures present (refer to 5.2). Maximum tolerable deviations with respect to time and temperature or temperature ranges are provided by the cell manufacturer.