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Draft Indian Standard

MEASUREMENT OF CYCLE LIFE AND ENERGY DENSITY FOR ADVANCED CHEMISTRY CELLS — METHOD OF TESTS
(*First Revision*)

(ICS 29.220.30)

Secondary Cells and Batteries Sectional Committee ETD 11

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1 SCOPE

This standard covers the method of measurement of cycle life and energy density for advanced chemistry cells (ACCs).

The test methods specified in this standard applies primarily to secondary lithium ion cells.

NOTES

1. The test methods specified in this standard can also be used for testing of other secondary cells falling under the definition of ACCs.
2. Additional test conditions for such secondary cells (that is, other than secondary lithium-ion cells), if any, shall be specified by the manufacturer.

2 REFERENCES

The standards listed below contain provisions which, through reference in this text, constitute provisions of this standard. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below.

IS No.	*Title*
IS 4905 : 2015	Random sampling and randomization procedures (*first revision*)

3 TERMINOLOGY

For the purpose of this standard, the following terms and definitions shall apply.

3.1 Advanced Chemistry Cells (ACCs)

The new generation technologies cells that can store electric energy either as an electrochemical or as a chemical energy and convert it back in the form of electric energy as and when required.

The cell technologies that demonstrate the cycle life and energy density, as mentioned in **Table 1**, will be classified as ACCs.

3.2 Energy Density

The amount of energy stored per unit weight of a cell and measured in Wh/kg.

Table 1 Advanced Chemistry Cells (ACCs)
(*Clause* 3.1)

Sl. No.	**Cycle Life**	**Energy Density** (Wh/kg)				
(1)	**(2)**	**(3)**				
		≥ 50	≥ 125	≥ 200	≥ 275	≥ 350
i)	≥ 1 000				ACC E4C1	ACC E5C1
ii)	≥ 2 000			ACC E3C2	ACC E4C2	ACC E5C2
iii)	≥ 4 000		ACC E2C3	ACC E3C3	ACC E4C3	ACC E5C3
iv)	≥ 10 000	ACC E1C4	ACC E2C4	ACC E3C4	ACC E4C4	ACC E5C4

3.3 Cycle Life

The number of charge and discharge cycles that a cell is able to support at a specified depth of discharge (DoD) before its capacity degrades to the end of life (EoL) condition.

3.4 State of Health (SoH)

The ratio of actual capacity of a cell and the initial rated capacity of the cell expressed as a percentage.

3.5 End-of-Life Capacity (EoL)

The minimum SoH of the cells, post which they cannot fulfill the application's requirements due to a significant reduction in performance.

3.6 Room Temperature

The temperature of 25 °C ± 2 °C.

3.7 Rate of Discharge (C-Rate)

A measure of the rate at which a cell is discharged or charged relative to its maximum capacity for example 1 C rate means that the discharge current will discharge the entire cell in 1 h and in the same cell discharging at 0.5 C would mean that discharge current will discharge the entire cell in 2 h.

3.8 Depth of Discharge (DoD)

The percentage of energy cycled out of the cell on a given cycle with respect to the total capacity of the cell. The DoD can also be referred to as the fraction of the cell capacity which is used in every charge and discharge cycle.

3.9 State of Charge (SoC)

It denotes the capacity which is currently available as a function of the rated capacity. The value of the SoC varies between 0 percent and 100 percent. If the SoC is 100 percent, then the cell is said to be fully charged, whereas a SoC of 0 percent indicates that the cell is completely discharged.

3.10 Rated Capacity

The capacity value of a cell determined under specified conditions and declared by the manufacturer.

3.11 Final Voltage

The voltage below which discharge is not permissible considering safety of the cell, as declared by the manufacturer.

3.12 End of Discharge Voltage

Voltage correspond to at least a DoD of 80 percent, as declared by the manufacturer.

3.13 Batch

All cell of the same type of design, chemistries, form factor, and rating manufactured by the same factory during the same period, using the same production process and materials, offered for inspection/sampling at a time, shall, constitute a batch.

3.14 Power Capability

Maximum power that a cell can deliver at a given voltage and specified SOC.

4 GENERAL

4.1 Only cell samples which are less than three months (90 days) old, from the date of manufacture, shall be used for the tests specified in this standard.

NOTES

1. Generally capacity of lithium ion cells gradually decreases.
2. The manufacturer shall inform the date of manufacture of the cells.

4.2 The ambient temperature shall be the room temperature. The cells received for testing shall be stored at a temperature of 25 °C ± 5 °C until taken up for testing.

4.3 Before each test, the cell temperature shall be stabilized at room temperature by soaking at a temperature of 25 °C ± 2 °C for a minimum of 12 h.

NOTES

1. Thermal stabilization of a cell is considered to be reached if after an interval of 1 h, the change of cell temperature is lower than 1 °C.
2. The soaking period of 12 h may be reduced if thermal stabilization is reached.
3. The cell temperature shall be measured either at the body or at the terminals.

4.4 Rate of Discharge (C-Rate)

The rate of discharge at which the energy density and cycle life tests are to be conducted shall be under standard test condition of 0.5 C charge and 0.5 C discharge unless otherwise specified by the manufacturer.

NOTE — The rate of charge/discharge specified by the manufacturer shall not be less than 0.5 C.

4.5 Charging Procedure for Test Purposes

Prior to charging, the cell shall be discharged at 25 °C ± 2 °C at a constant C-rate, as per **4.4**, down to a specified final voltage as declared by the manufacturer.

After the discharge, the cell shall be stored, in an ambient temperature of 25 °C ± 2 °C, for the rest duration, as specified by the manufacturer or customer.

The charging procedure for test purposes shall be carried out at an ambient temperature of 25 °C ± 2 °C, using the method declared by the manufacturer.

4.6 Mass Measurement

The mass of a cell is measured at room temperature up to three significant figures with the tolerances specified in **5.**

4.7 Depth of Discharge (DoD)

The minimum DoD for testing shall be 80 percent. Testing at any other higher DoD level is permissible, if declared by the manufacturer. The cycle life and energy density tests shall be carried out at the same level of end of discharge voltage.

5 PARAMETER MEASUREMENT TOLERANCES

The overall accuracy of controlled or measured values, relative to the specified or actual parameters, shall be within the tolerances given below.

a) ± 1 percent for voltage;

b) ± 1 percent for current;
c) ± 2 °C for temperature;
d) ± 0.1 percent for time; and
e) ± 0.1 percent for mass.

NOTES

1. These tolerances take into account the combined accuracy of the measuring instruments, the measurement technique used, and all other sources of error in the test procedure.
2. The details of the instrumentation used shall be provided while reporting the test results.

6 ENERGY CAPACITY MEASUREMENT (in Wh)

The energy capacity of a cell shall be measured in accordance with the following.

Step 1 — The cell shall be charged in accordance with 4.5.

Step 2 — The cell shall be stored, in an ambient temperature of 25 °C ± 2 °C, for the duration specified by the manufacturer or customer.

NOTE — The cell shall be at rest period during step 2.

Step 3 — The cell shall be discharged in an ambient temperature of 25 °C ± 2 °C at a constant C-rate, in accordance with **4.4,** to the end-of-discharge voltage that is provided by the cell manufacturer.

Step 4 — Measure the discharge duration until the specified end-of-discharge voltage is reached. Calculate the discharge capacity of cell expressed in Ah up to three significant figures, by multiplying the discharge current (A) with the discharge duration (h).

NOTES

1. The rated capacity shall be reached within 03 discharges subsequent to the initial charge, if not met on the first discharge. Once the rated capacity has been met on any discharge, further discharge cycles for capacity shall not be continued.

2. The cell shall be considered as fail and the test shall be terminated in case:

   a) The measured capacity is less than the rated capacity even after 03 discharges subsequent to the initial charge; or

   b) The measured capacity exceeds the rated capacity by more than 20 percent.

Step 5 — Average voltage calculation the value of the average voltage during discharging shall be obtained by integrating the discharge voltage over time and dividing the result by the discharge duration. The average voltage is calculated using the following method.

Discharge voltages U_1, U_2, U_n are noted every 5 s from the time the discharging starts and voltages that cut off the end-of-discharge voltage in less than 5 s are discarded. The average voltage U_{avr} is then calculated in a simplified manner using equation (1) up to three significant figures by rounding off the result.

$$U_{avr} = \frac{U_1+U_2+\cdots+U_n}{n} \text{ .... (1)}$$

Step 6 — The energy capacity expressed in W_h shall be calculated using equation (2) up to three significant figures by rounding off the result.

$$W = C_d \times U_{avr} \text{ .... (2)}$$

where

W = energy capacity of the cell at room temperature (W_h) when discharged underspecified conditions;
C_d = discharge capacity (A_h) as calculated in Step 4;
$U_{av}r$ = average voltage during discharging (V) as calculated in Step 5.

7 CALCULATION OF GRAVIMETRICENERGY DENSITY

7.1 Mass Measurement

Mass of the cell shall be measured in accordance with **4.6**.

7.2 Energy Capacity Measurement

Energy capacity of the cell shall be determined in accordance with **6** at room temperature.

7.3 Gravimetric Energy Density Calculation

The gravimetric energy density shall be calculated using equation (3) up to three significant figures by rounding off the result.

$$P_{ed} = \frac{W}{m} \text{ .... (3)}$$

where

P_{ed} = gravimetric energy density (W_h/kg);
W = energy capacity of the cell at room temperature (W_h) when discharged underspecified conditions, determined in accordance with clause **7.2**.
m = mass of the cell (kg), determined in accordance with clause **7.1**.

7.4 Process **7.2** and **7.3** shall be repeated five times. The final result shall be calculated by taking average of best three readings.

NOTE — Discharge as per clause 4.5 is envisaged while calculating energy density for the first time only, and need not required in subsequent 4 iterations.

8 TEST METHOD FOR CYCLE LIFE MEASUREMENT

A cell is generally chosen based on its high energy density and good power capability at the desired working voltage. However, the reliability of a cell depends on its ability to deliver the expected cycle life in the long run. High discharge currents can significantly reduce the cycle life of cells. The following steps illustrate the procedure for undertaking cycle life testing through a series of charge and discharge cycles. Before the charge and discharge cycle test, measure the energy capacity as the initial performance of the cell in accordance with **6** at 25 °C ± 2 °C.

8.1 Charge and Discharge Cycle

The charge and discharge cycle test shall be performed as follows.

a) At the start of the test, cell temperature shall be stabilized to 25 °C ± 2 °C in accordance with **4.3.**

b) Test phases

Phase 1 – The cell shall be discharged at 25 °C ± 2 °C at a constant C-rate, in accordance with **4.4**, down to a specified final voltage. The final voltage shall be the same as that declared by the manufacturer.

Phase 2 – The cells shall be fully charged, in an ambient temperature of 25 °C ± 2 °C, by the method specified by the cell manufacturer. The charge time shall be less than 2 h for the constant current charging step.

Phase 3 – The cell shall be discharged, in an ambient temperature of 25 °C ± 2 °C at constant C-rate, in accordance with **4.4**, until its voltage is equal to the end-of-discharge voltage that is provided by the cell manufacturer.

Phase 4 – Phase 2 and 3 shall be repeated until the test termination specified in **8.1(d).**

NOTE **—** The rest time between each phase shall be as specified by the cell manufacturer.

c) Periodical measurement of performance

After completion of every 100 cycles, the energy capacity of the cell shall be measured in accordance with **6.**

d) Termination of test

The cycle life test shall be terminated when either of the following conditions is satisfied.

Condition A – The test sequence from phase 2 to phase 4 has been repeated for equal number of cycles as declared by the cell manufacturer.

Condition B – Energy capacity determined as per clause **8.1** (c) is decreased to less than 80 percent of the observed value in the first cycle as per step **4** of **6**.

NOTE **—** If the voltage falls below the lower limit specified by the cell manufacturer during phase 3, the test shall be discontinued notwithstanding the stipulation in **8.1(d)**, and the cell performance shall be measured at this point as specified in **8.1(c)**.

8.2. High Rate Discharge Test

8.2.1 *Life Cycle Testing*

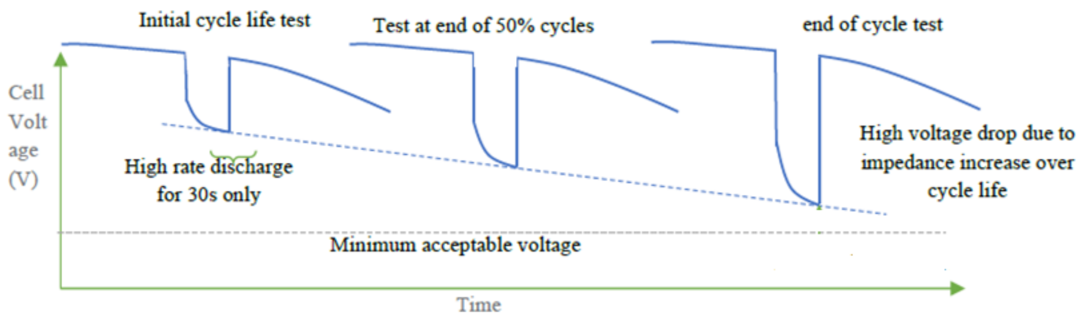
As per clause 8.1, shall include a high - rate discharge test to ensure that the cell, under testing, can deliver rated power/ C-rate till the end of life of cell, apart from maintaining the rated energy (kwh) capacity. Considering the same, the power capability of the cell shall be measured using a high rate discharge or high -rate pulse discharge test.

8.2.2 *The Cell Under Life Cycle Testing*

Will need to pass high rate discharge test by demonstrating that the cell voltage after application of the high current pulse shall not fall below the manufacturer determined end of discharge voltage /minimum acceptable voltage as highlighted in the graph below.

8.2.3 *Methodology of High Rate Discharge Test*

High rate discharge test shall be conducted by applying a high current pulse of 30 s duration while the cell is going through a normal discharge test, during life cycle test. The parameters to be measured are as shown by the following illustration:



NOTE — Manufacturer should define the minimum acceptable voltage level. The "manufacturer specified" 30 s peak discharge current value shall be used for the test.

8.2.4 *It Is Recommended That This Test*

Shall be conducted at a temperature of 25 °C ± 2 K and SoC of the cell below 50 percent but above 40 percent. The test should not be performed at below 40 percent SoC since the cell may not be able to deliver the required power at SoC levels below it.

8.2.5 *Power Capability Calculation*

The Power capability or Power Capacity of the cell shall be calculated according to equation (4) and rounded to 3 significant figures.

$$P_d = U_d \text{ X } Id_{max} \text{ --- equation (4)}$$

where

P_d is the Power Capability (W);

U_d is the measured cell voltage at the end of the 30 s pulse of Id_{max} discharge (V);

Id_{max} is the maximum discharge current which is specified by the manufacturer (A).

8.3 Minimum Performance Requirements of the Cell

It is recommended that the test results from life cycle test and high rate discharge test, cover the following parameters as minimum performance requirements of the cell:

a) Energy delivered at the start of cycle life, at end of 50 percent of specified cycle life and at end of specified number of cycles/EOL capacity/end of cycle life test should be at or above 100 percent, 90 percent and 80 percent of the rated energy capacity, respectively.

b) Power capability determined as per clause **8.2.5**, at the start of cycle life, at end of 50 percent of specified cycle life and at end of specified number of cycles/EOL capacity/end of cycle life test should be at or above the corresponding manufacturer specified values.

c) The cell needs to demonstrate minimum acceptable voltage level through a high-rate discharge test as per clause **8.2.2**, at the start of cycle life, at end of 50 percent of cycle life and at end of specified number of cycles/EOL capacity/end of cycle life test.

9 SAMPLING

9.1 Sampling and Testing

9.1.1 *Collection of Samples*

9.1.1.1 For the purpose of this clause, the definitions given in **IS 4905** shall apply.

9.1.1.2 The sample size should be at least four times the number of units required for testing, to take into account probable damages due to transportation and possible repetition of tests upon failure in a test. The number of cells required for each test shall be 05.

Explanatory NOTE **—** If the total number of exclusive cells required for all the tests is n, the sample size will be n. The four samples will totally contain 4 x n cells. Only the first sample set out of the four selected sample sets need be submitted for testing. The other three sets totaling 3 x n cells are to be kept as back up for the above mentioned exigencies. If only five cells are required for each test and all the tests can sequentially be completed on those five cells then n will be 5.

9.1.1.3 The sample should be drawn from cells which have completed manufacture, inclusive of all quality assurance programmers of the manufacturer, but before their assembly into batteries. The sample shall be drawn from batches which are not more than 3 months old.

9.1.1.4 The sample shall be collected as per method 1 in clause **8.6** of **IS 4905** from the production where the identification of the units shall be by their serial numbers.

Batch/lot size or “N” units according to clause **8.6** of **IS 4905** shall be as agreed between manufacturer and customer/regulatory authority/responsible agency.

Random numbers for the purposes shall be generated as per algorithm at clause **7** of **IS 4905**.

Audit records as per clause **7.4** of **IS 4905** shall be maintained by the manufacturer for audit purposes by a responsible authority or regulatory body **9.1.2** criteria for acceptance.

All units of a selected sample shall pass the tests. In case a sample fails (results fall outside the eligibility matrix) in any of the tests, a further sample consisting of double the number of units should be tested for all the tests. All units of this second sample shall pass in the tests.

9.2 Guidance on Samples

9.2.1 Cells are subject to degradation in storage due to a variety of chemical mechanisms, such as limited thermal stability of materials in storage. Battery performance can degrade during use, due to parasitic reactions. Rates of degradation can be related to a number of factors, such as storage temperature or temperature variations.

9.2.2 The effect of degradation of performance can be estimated by real time storage measurements or by accelerated ageing at high temperatures.

9.2.3 Hence, the selection of cells as per clause **9.1.1.3** to be done exclusively from the fresh batch of manufacturing.

10 REPORTING AND TEST REPORTS

10.1 Reporting and Records

Laboratories shall ensure following minimum reporting and record maintenance requirements.

a) Status/details of sample physical fitness
b) Sample receiving date,
c) Testing and completion date,
d) Test conformance details,
e) Progress report along with the test reports and its observed values,
f) Status of failures,
g) Analysis of trends etc.

Raw test data/trends of test readings to be maintained for verification by customer/manufacturer/responsible agency.

10.2 Test Reports

Following details to be included in test reports as a minimum.

10.2.1 *General Identification Details*

Manufacturer name, cell model, cell rating, cell form factor, cell serial no., charge/discharge current, end of discharge voltage, maximum voltage, rest duration between charge-discharge cycle, charging method, charge/discharge rate, ambient temperature, DoD level, specified life cycles.

10.2.2 *Energy Density Test*

For each cycle: cell voltage , change/discharge current, cell body temperature, average voltage, discharge capacity, energy capacity, mass of cell, energy density, final energy density.

10.2.3 *Life Cycle Test*

For each cycle: cell voltage , change/discharge current, cell body temperature, cell voltage after discharge up to DOD periodic measurement of energy capacity, energy capacity at 50 percent specified life cycles, life cycle at termination of test.

10.2.4 *High Rate Discharge Test*

Specified magnitude of pulse, specified SOC level, specified minimum acceptable voltage (at initial cycle, 50 percent of specified cycles and end of life cycle), specified power capability at initial, 50 percent of life cycles and end of life cycles, duration of pulse, actual magnitude of pulse, actual voltage after 30 s current pulse and, power capability (at initial, 50 percent of life cycles and end of life cycles).