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Guidelines for principal component reliability testing for LED light sources and LED luminaires

National foreword

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

GUIDELINES FOR PRINCIPAL COMPONENT RELIABILITY TESTING FOR LED LIGHT SOURCES AND LED LUMINAIRES

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62861, which is a Technical Specification, has been prepared by subcommittee 34A: Lamps, of IEC technical committee 34: Lamps and related equipment.

The text of this Technical Specification is based on the following documents:

Enquiry draft	Report on voting
34A/1884/DTS	34A/1966/RVDTS

Full information on the voting for the approval of this technical specification 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.

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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

LED products depend generally on how balanced its principal components are in terms of their reliability. It is not only the LED components that determine product performance, but also other parts of the LED product play an equally important role. For instance, electronic subassemblies, optics, mechanics and the involved cooling method play such a role.

This Technical Specification envisions a methodology, which addresses separate subcomponent reliability data, to provide a basis for statistical system reliability design. Standardized reporting formats and flowcharts are presented.

Next, protocols based on accelerated methods are given to estimate system reliability of the final product using subcomponent data.

Verification of LED product lifetime is based on a ‘test to pass’ principle, which means the components of the product under test are evaluated to give equivalent reliability confidence to that which would be achieved by real-time life testing of the complete LED product. The tests described in this Technical Specification are divided into: initial qualification tests (IQT) giving confidence of basic component robustness, but not linked to any specific lifetime projection, and accelerated stress tests (AST) giving confidence of reliability to a specific lifetime (within the specified constraints of the test).

Since the approach foreseen in this Technical Specification covers a generic methodology, it can be seen as guidance related to relevant product performance standards, such as the LED lamp performance standard IEC 62612, the LED module performance standard IEC 62717 and LED luminaire performance standard IEC 62722-2-1. This Technical Specification is not recommended for use as a normative reference to the LED product performance standards.

This Technical Specification addresses the need for a document giving guidance that is developed according to consensus procedures and in itself is normative in nature, while at the same time recognizing that LED technology for lighting products is still in an emerging phase. This Technical Specification approaches an International standard in terms of detail and completeness.

GUIDELINES FOR PRINCIPAL COMPONENT RELIABILITY TESTING FOR LED LIGHT SOURCES AND LED LUMINAIRES

1 Scope

This Technical Specification provides guidelines for establishing confidence in product reliability using principal component testing for LED light sources and LED luminaires for general lighting. It includes methods and criteria using initial qualification tests and accelerated stress tests of the principal components. The performance of any principal component will influence the performance of the final product.

Techniques to validate full lifetime claims and lumen maintenance projection are outside the scope of this Technical Specification.

The following principal components are included in the testing if they are used as an integral part for the LED light source or LED luminaire:

- LED package and interconnects;
- optical materials;
- electronic subassemblies;
- cooling systems, both active (e.g. fans) and passive (e.g. thermal interface material);
- construction materials.

This Technical Specification is not recommended for use as a normative reference to the LED product performance standards.

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 60068-2-20:2008, *Environmental testing – Part 2-20: Tests – Test T: Test methods for solderability and resistance to soldering heat of devices with leads*

IEC 60068-2-27:2008, *Basic environmental testing procedures – Part 2: Tests – Test Ea and guidance: Shock*

IEC 60068-2-30:2005, *Environmental testing – Part 2-30: Tests – Test Db: Damp heat, cyclic (12 h + 12 h cycle)*

IEC 60068-2-42:2003, *Environmental testing – Part 2-42: Tests – Test Kc: Sulphur dioxide test for contacts and connections*

IEC 60068-2-43:2003, *Environmental testing – Part 2-43: Tests – Test Kd: Hydrogen sulphide test for contacts and connections*

IEC 60068-2-58:2015, *Environmental testing – Part 2-58: Tests – Test Td: Test methods for solderability, resistance to dissolution of metallization and to soldering heat of surface mounting devices (SMD)*

IEC 60068-2-60:2015, *Environmental testing – Part 2-60: Tests – Test Ke: Flowing mixed gas corrosion test*

IEC 60529:2013, *Degrees of protection provided by enclosures (IP Code)*

IEC 60929:2011, *AC and/or DC-supplied electronic control gear for tubular fluorescent lamps – Performance requirements*
IEC 60929:2011/AMD1:2015

IEC 62504, *General lighting – Light emitting diode (LED) products and related equipment – Terms and definitions*

ANSI/ESDA/JEDEC JS-001-2014, *Electrostatic discharge sensitivity testing human body model (HBM) – Component level*

ASTM D5470 – 12, *Standard test method for thermal transmission properties of thermally conductive electrical insulation materials*

ASTM D7027 – 13, *Standard test method for evaluation of scratch resistance of polymeric coatings and plastics using an instrumented scratch machine*

ASTM E595 – 07, *Standard test method for total mass loss and collected volatile condensable materials from outgassing in a vacuum environment*

IPC-9591, *Performance parameters (mechanical, electrical, environmental and quality/reliability) for air moving devices*

J-STD-002D, *Solderability tests for component leads, terminations, lugs, terminals and wires*

J-STD-020E, *Moisture/reflow sensitivity classification for nonhermetic surface mount devices*

JESD22-A101C, *Steady-state temperature humidity bias life test*

JESD22-A104D, *Temperature cycling*

JESD22-A108D, *Temperature, bias, and operating life*

JESD22-A113F, *Preconditioning of plastic surface mount devices prior to reliability testing*

JESD22-B103B, *Vibration, variable frequency*

JESD51-51, *Implementation of the electrical test method (static test method) for the measurement of the real thermal resistance and impedance of light emitting diodes with exposed cooling surface*

MIL-C-48497A, *Durability requirements for coating, single or multilayer, interference*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62504 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
acceleration factor

AF

ratio of the time it takes for a certain fraction of the population to fail, following application of one stress or use condition, to the corresponding time at a more severe stress or use condition

Note 1 to entry: The failure mode and the type of the failure distribution (lognormal, Weibull, exponential or alike) within the two stress conditions should be identical.

Note 2 to entry: Acceleration factors can be calculated for several stresses that can affect the reliability of the unit under test, such as temperature, electrical, mechanical loads, light exposure, chemical, moisture or other stresses. Annex B presents commonly known acceleration models.

3.2
activation energy

E_{a}

excess free energy over the ground state that is required in order that a particular process occurs

Note 1 to entry: The activation energy is used in the Arrhenius equation for the thermal acceleration.

3.3
Boltzmann's constant

k_{B}

constant equal to 1,381 × 10^{-23} J/K or 8,617 × 10^{-5} eV/K

Note 1 to entry: Boltzmann's constant is used in the Arrhenius equation.

3.4
failure mechanism

process that leads to failure

Note 1 to entry: The process may be physical, chemical, logical, or a combination thereof.

[SOURCE: IEC 60050-192:2015, 192-03-12.]

3.5
failure mode

manner in which failure occurs

Note 1 to entry: A failure mode may be defined by the function lost or other state transition that occurred.

[SOURCE: IEC 60050-192:2015, 192-03-17, modified – do not use the wording "DEPRECATED: fault mode".]

3.6
failure rate

probability that a system will fail during the next specified time increment, given that it has survived up to the current point in time

Note 1 to entry: The failure rate of a system usually depends on time, with the rate varying over the lifecycle of the system.

Note 2 to entry: Failure rate is expressed in % failures per time unit.

3.7
application profile
mission profile
user profile
profile describing the environmental loads that are imposed upon the product under normal operation conditions

Note 1 to entry: Annex A presents two example application profiles.

3.8
mean time to failure
MTTF
average period of time for a system to operate without failure

3.9
power factor
ratio of the real power flowing to the load to the apparent power in the circuit

3.10
reliability
<of an item> ability to perform as required, without failure, for a given time interval, under given conditions

Note 1 to entry: The time interval duration may be expressed in units appropriate to the item concerned (e.g. calendar time, operating cycles, distance run) and the units should always be clearly stated.

Note 2 to entry: Given conditions include aspects that affect reliability, such as: mode of operation, stress levels, environmental conditions, and maintenance.

Note 3 to entry: Reliability may be quantified using measures defined in Section 192-05, Reliability related concepts: measures.

[SOURCE: IEC 60050-192:2015, 192-01-24.]

3.11
sample size
representative quantity of units under test extracted from a batch of reference units

3.12
system
set of interacting or interdependent components forming an integrated whole

3.13
system reliability
probability that a system, including all hardware, firmware, and software, will satisfactorily perform the task for which it was designed or intended, for a specified time and in a specified environment

3.14
solder point temperature
t_s
temperature of the point near the LED package interconnect as specified by the manufacturer of the package

3.15
cooling performance
function of a device providing cooling in an amount to maintain the performance of the component to which it pertains

3.16
Weibull distribution

continuous probability distribution described by two parameters: scale parameter α and shape parameter β

3.17
accelerated stress test
AST

test for which a reliability model exists for assessing reliability over a shorter time period than a test under normal application conditions by applying an accelerating stress factor

Note 1 to entry: The reliability model can apply to components and materials.

3.18
initial qualification test
IQT

test to demonstrate a basic level of robustness by applying a non-accelerating stress factor

Note 1 to entry: An IQT is employed when an accelerated reliability model is not appropriate.

3.19
validated AST time

mathematical product of the AST duration used for validation and the acceleration factor

4 Component test conditions

Clauses 5, 6, 7, 8 and 9 specify minimum stress-test driven qualification and reliability requirements for the principal components of LED products. It includes references to test conditions for each component. The purpose is to give guidance for establishing a level of reliability for which a product is specified. What the exact level is depends on the product specification and depends on the application profile. Stress test qualification of the principal components is defined as successful completion of the test requirements outlined in each clause for each principal component. Each clause specifies a set of qualification tests that shall be considered for new LED product qualifications. In case of requalification associated with a design or process change, a limited set of qualification tests may be considered.

This Technical Specification describes two types of qualification tests. A test for which a reliability model exists is called an accelerated stress test (AST) for assessing reliability results over a much shorter test time period. When a reliability model is not appropriate, then the test is termed an initial qualification test (IQT) and used to demonstrate a basic level of robustness. Tests in this Technical Specification are classified as either IQT or AST. The stressors or loads that are imposed upon LED products in two example environmental conditions are described in Annex A. These stressors also apply to the principal components.

NOTE In general, it is assumed that passing the harsher test conditions implies that the more relaxed conditions would also be passed.

For principal components that have failed the acceptance criteria of tests required by this Technical Specification, it is recommended to understand the failure mechanism, determine the root cause and take corrective actions. To confirm that the failure mechanism is understood and contained, and appropriate corrective and preventive actions are effective, it is recommended to repeat the applicable qualification test(s) successfully.

This Technical Specification makes reference to other IEC standards or standards from other organizations. Where relevant, further details on the tests can be found in these documents. Test conditions in this document may deviate from test conditions in the reference documents. In such a case, further specifications in the reference document should still be applied as appropriate.

5 LED package and interconnects

5.1 General

The purpose of Clause 5 is to determine that an LED package is capable of passing the specified stress tests and thus can be expected to give a certain level of reliability in general lighting applications. LED packages and interconnects of different types exist. There is currently no official LED classification; they can be classified by colour (red, orange, blue, green), mechanical outline (round, square, rectangular, surface), by materials used (full epoxy resin packaging, metal base, ceramic base epoxy resin packaging and glass packaging)[1] and/or by luminous intensity (general, high-brightness, ultra-high brightness). While it is not the intention of this Technical Specification to specify an LED classification, the following are different common types of LED packages:

- high-power LEDs (includes high-brightness):
  - wire-bonded types;
  - flip-chip types;
  - wafer level chip types.
- mid-power LEDs:
  - mainly wire-bonded types;
  - chip-on-board types (usually not reflow or wave soldering but mechanically mounted).
- lower-power LEDs:
  - mainly wire-bonded types.

Subclauses 5.11, 5.12 and 5.13 specify a set of qualification tests that shall be considered for new LED package and interconnects qualifications. Where appropriate, family qualifications can be done, according to:

- same chip technology in different LED packages;
- same phosphor systems in different LED packages;
- same package footprint in different LED packages.

An example qualification flowchart is depicted in Figure D.1.

5.2 Sampling requirements

Unless specified otherwise, a total of at least 30 LED packages taken from three different batches of 10 each shall be used. For family qualification, the three different batches shall be considered to represent the variety of the qualification family.

Exceptions to the specified sample size shall be noted with the reasoning that justifies equivalent reliability still being demonstrated. This may be appropriate where multiple LED dies are incorporated in the package, for example chip-on-board devices.

5.3 Production requirements

All qualification LED packages shall be produced on tooling and processes representative for those that will be used to support LED package deliveries at projected production volumes. Sample details shall be reported in the principal component test report (Annex F).

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[1] Adapted from source: LEDinside, with the permission of the author(s).

5.4 Assembly of LED packages on test boards

LED packages may need to be assembled on test boards. An appropriate choice of test board, interconnect material and process shall be made by the manufacturer. The choice of test board, interconnect material and process shall be documented for each individual test in the principal component test report (Annex F).

5.5 Moisture preconditioning

Moisture preconditioning is applicable to surface-mountable devices designed for reflow soldering. LED packages shall be subjected to moisture preconditioning according to J-STD-020E for tests specified in 5.11.2.1, 5.11.2.2, 5.11.2.3, 5.11.3.1, 5.11.4.1 and 5.11.4.2. The choice of the preconditioning level shall be documented for each individual test in the principal component test report (see Annex F). The initial electrical and photometric test (see 5.7) shall be executed after the moisture preconditioning.

5.6 Thermal characteristics

The value of either the solder point temperature (t_{s}), junction temperature (t_{j}) or thermal resistance (R_{Θ}) shall be determined according to JESD51-51.

5.7 Pre- and post-stress electrical and photometric requirements

Electrical and photometric values shall be measured at the test conditions as specified in the product specification before and after stress testing. Intermediate measurements (read points) are permitted and may be used for diagnostic purposes. All LED packages used for qualification shall meet the product specification parameters measured at the test conditions before stress testing. LED packages shall be tested at the operating current specified in the appropriate LED package specification (manufacturer datasheet) prior to and after the qualifications tests. The following parameters shall be measured:

- luminous flux or radiant power (whichever is appropriate);
- forward voltage;
- colour coordinates or dominant/peak wave length (whichever is appropriate).

5.8 Pre- and post-stress visual inspection

The construction, marking and finishing of the LED package should be inspected according to JESD22-B101B prior to and after the qualification tests.

5.9 Solderability and resistance to soldering heat

5.9.1 Solderability

The objective of the solderability test is to verify the solderability of the devices. This verification is made on the ability of the pins to be wetted or coated by solder. The solderability of the LED package shall be tested and meeting the compliance criteria according to IEC 60068-2-58. The solderability of the LED package with leads shall be tested and meet the compliance criteria according to IEC 60068-2-20. Alternatively J-STD-002D may be applied.

5.9.2 Resistance to soldering heat (RSH-reflow) test

The objective of the resistance to soldering heat test is to evaluate the performance of the LED package under stress due to soldering heat. The LED package shall be tested and meet the compliance criteria according to J-STD-020E. This test applies only to LED packages that are specified for reflow soldering.

5.10 Failure criteria

The LED package and interconnects principal components are considered to have failed if any of the following criteria applies for each item in the test.

a) Forward voltage V_f at the specified operating current I_f deviates by more than ±15 % from the initial value. Radiant power or luminous flux or intensity at the specified operating current I_f deviates by more than ±20 % from the initial value.

b) Chromaticity ($u'v'$) at the specified operating current I_f of LED packages emitting white light after the qualification test deviates by more than 0,006 from the initial value, where $\Delta u'v'$ = SQRT($(\Delta u')^2 + (\Delta v')^2$).

   NOTE $\Delta u'$ and $\Delta v'$ are defined in ISO 11664-5:2009.

c) The LED package exhibits externally visible physical damage attributable to the qualification test. However, if the cause of failure is agreed to be due to mishandling or electrostatic discharge (ESD), the failure shall not be counted, but reported as part of the principal component test report.

d) The LED package interconnects to the test board failed, visually observed with zero light output. Perform cross-sectional analysis on failed samples in order to discriminate other failure modes from solder joint failures (Annex E).

For LED packages a destructive physical analysis (DPA) should be performed according to Annex E on two random samples of surviving units after completion of the following tests where applicable according to the application profile: TMCL test, WHTOL test and H2S test.

For LED package interconnects a destructive physical analysis (DPA) should be performed according to Annex E on two random samples of surviving units after completion of the following tests where applicable according to the application profile: TMCL test and VVF test. The post electrical and photometric test of these samples shall be executed before the destructive physical analysis.

It is recommended that failures found during the qualification test be fully investigated until the root cause is found.

5.11 Initial qualification tests for LED packages

5.11.1 General

The initial qualification tests for LED packages are grouped as follows:

- temperature and operation stress:
  - Low temperature operating life (LTOL);
  - High temperature operating life (HTOL);
  - Pulsed operating life (PLT).
- thermo-mechanical stress:
  - Temperature cycling (TMCL);
  - Vibrations variable frequency (VVF).
- temperature and humidity stress:
  - Wet high temperature operating life (WHTOL);
  - Damp heat cycling (DHC).
- electrical stress:
  - Electrical stress – ESD-HBM.
- environmental stress:
  - Hydrogen sulphide (H2S);

- Flowing mixed gas corrosion (FMGC);
- SO2 test (SO2).

5.11.2 Temperature and operation stress

5.11.2.1 Low temperature operating life (LTOL)

The purpose of this IQT is to evaluate the performance of the LED package under stress due to low ambient temperature (t_{amb}) operation. The test shall be conducted according to JESD22-A108D; the following test conditions apply:

- duration 1 000 h;
- $t_{\mathrm{amb}} = -40$ °C.

The LED package shall be operated at the corresponding maximum rated operating current and t_{s}, t_{j} or R_{Θ} shall be reported.

Compliance is checked by applying the failure criteria of 5.10 to the test results obtained from the pre- and post-stress tests according to 5.7 and 5.8.

5.11.2.2 High temperature operating life (HTOL)

The purpose of this IQT is to evaluate the performance of the LED package under stress due to high temperature operation. The test shall be conducted according to JESD22-A108D; the following test conditions apply.

For each test condition, a minimum total of 78 LED packages taken from 3 different batches of 26 each shall be used:

- duration 1 000 h;
- testing shall be done at:
  - the maximum operating current at the corresponding allowed t_{amb}; and
  - the maximum t_{amb} with the corresponding allowed operating current.

NOTE The maximum operating current and the maximum t_{amb} can occur at the same condition.

In all cases t_{s}, t_{j} or R_{Θ} shall be reported.

Compliance is checked by applying the failure criteria of 5.10 to the test results obtained from the pre- and post-stress tests according to 5.7 and 5.8.

5.11.2.3 Pulsed operating life (PLT)

The purpose of this IQT is to evaluate the performance of the LED package under stress due to pulsed operation, for example for pulsed width modulation. The LED package shall be tested according to JESD22-A108D, the following test conditions apply:

- duration 1 000 h;
- $t_{\mathrm{amb}} = 55$ °C;
- pulse width 100 µs, duty cycle 3 %.

The LED package shall be operated at the corresponding maximum rated operating current.

Compliance is checked by applying the failure criteria of 5.10 to the test results obtained from the pre- and post-stress tests according to 5.7 and 5.8.

5.11.3 Thermo-mechanical stress

5.11.3.1 Temperature cycling (TMCL)

The purpose of this IQT is to evaluate the performance of the LED package, chip and wire/chip bond integrity under mechanical stress due to extreme temperature cycles without operation of the LED package. The LED package shall be tested according to JESD22-A104D. A minimum total of 78 LED packages taken from three different batches of 26 each shall be used. The following test conditions apply:

- duration with a minimum of 500 cycles;
- soak mode 4 (minimum soak time 15 min).

The following minimum and maximum temperatures for t_{amb} shall be chosen by the manufacturer:

- TMCL condition: $t_{\mathrm{amb,min}}$ = −40 °C; $t_{\mathrm{amb,max}}$ as specified by the manufacturer with the minimum value of 85 °C.

The TMCL condition closest to the manufacturer’s operating temperature range according to the appropriate LED package specification (application profile, manufacturer datasheet) shall be chosen unless the manufacturer wishes to test compliance with a more severe cycle condition. The choice of the TMCL cycle condition and the transfer time shall be reported.

Compliance is checked by applying the failure criteria of 5.10 to the test results obtained from the pre- and post-stress tests according to 5.7 and 5.8.

5.11.3.2 Vibrations variable frequency (VVF)

Testing the LED packages under variable frequency vibrations is in general executed when mounted on a printed circuit board. Subclause 5.12 describes the test parameters accordingly.

Preconditioning according to 5.5 is not required.

Compliance is checked by applying the failure criteria of 5.10 to the test results obtained from the pre- and post-stress tests according to 5.7 and 5.8.

5.11.4 Temperature and humidity stress

5.11.4.1 Wet high temperature operating life (WHTOL)

The purpose of this IQT is to evaluate the performance of the LED package under stress due to temperature and humidity during operation. Temperature, humidity and operating current are used to accelerate the penetration of moisture through any protective material to reveal corrosion or migration mechanisms caused by material incompatibility, misprocessing or mishandling which may lead to reduced reliability. The LED package shall be tested according to JESD22-A101C. A minimum total of 78 LED packages taken from 3 different batches of 26 each shall be used. The following test conditions apply:

- duration 1 000 h;
- t_{amb} = 85 °C;
- 85 % relative humidity;
- power cycle 1 h on/1 h off.

The tests shall be performed at the corresponding maximum rated operating current (i.e. rating at t_{amb} = 60 °C or t_{amb} = 85 °C).

Compliance is checked by applying the failure criteria of 5.10 to the test results obtained from the pre- and post-stress tests according to 5.7 and 5.8.

5.11.4.2 Damp heat cycling (DHC)

The purpose of this IQT is to evaluate the performance of the LED package under stress due to temperature and humidity cycling. The LED package shall be tested according to IEC 60068-2-30, the following test conditions apply:

- −10 °C/25 °C dry;
- 25 °C/65 °C, 90 % relative humidity;
- 10 cycles;
- 24 h/cycle.

Compliance is checked by applying the failure criteria of 5.10 to the test results obtained from the pre- and post-stress tests according to 5.7 and 5.8.

5.11.5 Electrical stress – ESD-HBM

Electrical stress is tested by an electrostatic discharge, human body model test (ESD-HBM). The objective of this IQT is to verify that the product is robust against electrostatic discharge as specified. The HBM simulates the electrostatic discharge which is typically observed during manual handling of devices by a person without any ESD protection. The LED package shall be tested according to ANSI/ESDA/JEDEC JS-001, using the human body model. The HBM ESD component classification level (voltage level) shall be reported in the principal component test report, see Annex F.

5.11.6 Environmental stress

5.11.6.1 General

Preconditioning according to 5.5 is not required.

The failure criterion in 5.10 a) for radiant power or luminous flux or intensity at the specified operating current does not apply. Instead, the radiant power or luminous flux or intensity shall not decrease by more than 30% from the initial value.

5.11.6.2 Hydrogen sulphide (H2S)

The objective of this IQT is to determine the corrosive influence of typical operating and storage environments.

The resistance to hydrogen sulphide shall be tested according to IEC 60068-2-43; the following test conditions apply:

- air temperature 25 °C;
- 75 % relative humidity;
- H_2S concentration: 10×10^{-6} to 15×10^{-6} vol/vol (parts per million), balance air;
- duration 504 h.

Compliance is checked by applying the failure criteria of 5.10 to the test results obtained from the pre- and post-stress tests according to 5.7 and 5.8.

5.11.6.3 Flowing mixed gas corrosion (FMGC)

The resistance to corrosive gas atmosphere shall be tested according to IEC 60068-2-60; the following IQT conditions apply:

- test method 4;
- air temperature 25 °C;
- 75 % relative humidity;
- concentrations:
  - H_2S concentration: 10 × 10^{-9} vol/vol (parts per billion), balance air;
  - NO_2 concentration: 200 × 10^{-9} vol/vol (parts per billion), balance air;
  - Cl_2 concentration: 10 × 10^{-9} vol/vol (parts per billion), balance air;
  - SO_2 concentration: 200 × 10^{-9} vol/vol (parts per billion), balance air;
- duration 500 h.

Compliance is checked by applying the failure criteria of 5.10 to the test results obtained from the pre- and post-stress tests according to 5.7 and 5.8.

5.11.6.4 SO_2 test (SO2)

The resistance to corrosive SO_2 atmosphere shall be tested according to IEC 60068-2-42; the following IQT conditions apply:

- duration 168 h;
- air temperature 25 °C;
- 75 % relative humidity;
- SO_2 concentration 25 × 10^{-6} vol/vol (parts per million), balance air.

Compliance is checked by applying the failure criteria of 5.10 to the test results obtained from the pre- and post-stress tests according to 5.7 and 5.8.

5.12 Initial qualification test for LED package interconnects – VVF

LED package interconnects are tested by a vibrations variable frequency test (VVF). The objective of this IQT is to determine the effect of vibration on component parts in the specified frequency range. The LED package shall be tested according to JESD22-B103B; the following test conditions apply.

Use a constant displacement of 1,5 mm (double amplitude) over the range of 20 Hz to 100 Hz and a 200 m/s^2 constant peak acceleration over the range of 100 Hz to 2 kHz.

Compliance is checked by 5.10.

5.13 Accelerated stress tests for LED package interconnects

5.13.1 General

Prediction models are needed to project the accelerated test conditions to the application profiles (Annex A). The available acceleration models are described in Annex B. Table 1 maps the qualification test for the LED package interconnects with the acceleration model that is applicable for this test.

Table 1 – Mapping the LED package interconnects qualification tests to the useable acceleration model with typical range of the acceleration factor

Qualification test	Acceleration model	Typical range of acceleration factor
Interconnect temperature cycling (TMCL)	Coffin-Manson or Norris-Landzberg	5 to 15

5.13.2 Interconnect temperature cycling (TMCL)

The objective of this AST is to demonstrate that the solder joints' integrity is stable against mechanical stress caused by extreme temperature variations. The TMCL condition closest to the manufacturer's operating temperature range according to the appropriate LED package specification (application profile, manufacturer datasheet) shall be chosen unless the manufacturer wishes to test compliance with a more severe cycle condition. The temperature change rate shall be between 10 °C/min and 15 °C/min. The choice of the TMCL cycle condition and including change rate shall be reported. The LED package interconnects shall be tested according to JESD22-A104D; the following test conditions apply:

- duration: according to Table 2;

Table 2 – Duration (cycles) of temperature application

Maximum solder point temperature range in application ° C	**Duration (number of cycles)**
$t_S \leq 75$	500
$75 < t_S \leq 85$	750
$85 < t_S \leq 90$	1 500
$90 < t_S \leq 95$	2 000
$95 < t_S \leq 100$	2 500
$t_S > 100$	> 3 000

- soak mode 4 (minimum soak time 15 min);
- TMCL condition for t_{amb}: −40 °C to the highest specified temperature with a minimum of 85 °C.

Compliance is checked by applying the failure criteria of 5.10 c) and 5.10 d) to the test results obtained from the pre- and post-stress tests according to 5.7 and 5.8.

6 Optical materials

6.1 General

The purpose of Clause 6 is to determine that an optical material is capable of passing the specified stress tests and thus can be expected to give a certain level of reliability in general lighting applications. Primary optics are an integral part of the LED package. Secondary optics are all other optical parts remote from the LED package. All secondary optical parts and components are considered, including:

- light-transmitting parts (e.g. lenses, diffusors):
  - polycarbonate;
  - polymethylmetacrylate (PMMA);
  - silicones.
- light-reflecting parts (e.g. reflectors):
  - dichroic-coated glass;
  - aluminium-coated glass;
  - aluminium-coated plastic;
  - white plastic/non-coated material;
  - metallic reflectors;
  - silver coated plastic;

- optical converters (e.g. remote phosphor and colour filters).

Excluded from this principal component are the optical components directly mounted to the LED package (primary optics); they are part of Clause 5. Main stressors for optical materials are: process-induced; temperature; humidity; light intensity; chemical attack and/or mechanical (see also Annex A). Subclauses 6.8 and 6.9 specify a set of qualification tests that shall be considered:

- when a new material is selected;
- when a new supplier is selected;
- when an existing supplier changes:
  - the process,
  - the list of materials/parts;
  - the manufacturing locations.

An example qualification flowchart is depicted in Figure D.2.

6.2 Optical material test samples

A minimum of three optical material samples from different batches shall be used for each qualification test. Optical test samples may have any geometrical size, but this shall be reported in the principal component test report (Annex F). The preferred sample geometry is a flat plate, with a 2,0 mm thickness.

All qualification optical materials shall be produced on tooling and processes representative for those that will be used to support LED product deliveries at projected production volumes. The process conditions for the optical materials from suppliers shall be recorded. Deviations shall be reported in the principal component test report (Annex F).

Test ovens/cabinets shall be clean to avoid contamination of the samples during qualification testing.

6.3 Moisture preconditioning

Moisture preconditioning shall be executed according to JESD22-A113F. The initial photometric tests according to 6.4 shall be executed before and after the moisture preconditioning.

6.4 Pre- and post-stress photometric measurements

At read points 0 h, 500 h and 1 000 h, the spectral transmittance and reflectance shall be measured. These measurements are a tool for evaluating the degradation of optical properties during the product aging process.

The transmittance of the samples is measured using a UV-Vis spectral photometer. 100 % transmission is calibrated with no sample in the beam (only air in the light path), 0 % transmission is calibrated by fully blocking the beam. Measurement according to ISO 13468-1 is allowed. The measurement accuracy of the transmittance in the range from 300 nm to 800 nm shall be within □0,2 %.

The reflectance of the samples is measured using a diffuse reflection spectrometer. 0 % reflection is calibrated with no sample in the beam (only air in the light path), 100 % reflection is calibrated by fully blocking the beam. The measurement accuracy of the reflectance in the range from 300 nm to 800 nm shall be within ±0,2 %.

6.5 Adhesion test

The adhesion of coatings on the samples shall be measured according to MIL-C-48497A using an adhesive tape or equivalent (advised is Scotch Super 33+[2] tape, for coatings showing hydrophobic surface, it is preferable to use a hydrophobic type of adhesive tape). This tape is applied to the coated surface and removed with a snap action; no visible portion of the coating shall be removed, disregarding pinholes.

NOTE Digs according to MIL-C-48497A are considered pinholes.

6.6 Pre- and post-stress visual inspection

The construction and finishing of the optical material should be inspected prior to and after the qualification tests in order to judge the visual state of the samples.

6.7 Failure criteria

The optical material principal components are considered to have failed if any of the following criteria applies for each item in the test.

- Maximum 10 % reduction in transmittance/reflectance at any wavelength (in 5 nm intervals) over the range 380 nm to 780 nm (compared to 0 h value).
- The optical material exhibits externally visible physical damage attributable to the qualification test. No visual or mechanical defects are allowed. This includes deformations and/or delamination, meaning that coatings shall show no evidence of flaking, peeling, cracking or blistering.
- The optical material exhibits an externally visible colour change (e.g. yellowing or browning).

Destructive physical analysis (DPA) should be performed for optical materials according to Annex E on two randomly selected samples of good units after completion of each test specified in 6.10, 6.11 and 6.12. The post photometric test of these samples shall be executed before the destructive physical analysis.

It is recommended that failures found during the qualification test be fully investigated until the root cause is found.

6.8 Initial qualification tests

6.8.1 Relative humidity (RH)

The purpose of this IQT is to evaluate the performance of coated glass material under stress due to relative humidity. The test shall be conducted according to the following test procedure:

- exposure to a temperature of 40 °C and > 93 % relative humidity;
- duration: 240 h;
- air dry and perform the adhesion test according to 6.5.

Compliance is checked by applying the failure criteria of 6.7 to the test results obtained from the pre- and post-stress tests according to 6.6.

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[2] Scotch® Super 33+ is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product. Equivalent products may be used if they can be shown to lead to the same results.

6.8.2 Boiling water (BW)

The purpose of this IQT is to evaluate the performance of coated glass material under stress due to boiling. The test shall be conducted according to the following procedure:

- exposure to boiling water for 10 min;
- air dry and perform the adhesion test according to 6.5.

Compliance is checked by applying the failure criteria of 6.7 to the test results obtained from the pre- and post-stress tests according to 6.6.

6.8.3 Oven water (OW)

The purpose of this IQT is to evaluate the performance of coated material under stress due to water ingress. The test shall be conducted according to the following procedure:

- samples are submerged for 15 min in deionized water;
- heated in an oven to 300 °C for 30 min;
- cool down to room temperature;
- air dry and perform the adhesion test according to 6.5.

Compliance is checked by applying the failure criteria of 6.7 to the test results obtained from the pre- and post-stress tests according to 6.6.

6.8.4 High temperature exposure (HTE)

The purpose of this IQT is to evaluate the performance of coated material under stress due to high temperatures. The test shall be conducted according to the following procedure:

- samples are subjected to a temperature of 250 °C;
- duration: 1 000 h;
- air dry and perform the adhesion test according to 6.5.

Compliance is checked by applying the failure criteria of 6.7 to the test results obtained from the pre- and post-stress tests according to 6.4 and 6.6.

6.9 Accelerated stress tests

6.9.1 Prediction models

Prediction models are needed to project the accelerated test conditions to the application profiles (Annex A). Some of the available acceleration models are described in Annex B. Table 3 maps the qualification tests for the optical materials with suitable models from Annex B for these tests.

Table 3 – Mapping of the optical-material related accelerated stress tests

Accelerated stress test	Acceleration model	Typical range of acceleration factor
Temperature and humidity (TH)	Peck model or generalized Eyring model	6 to 60
Temperature and light exposure (TL)	Generalized Eyring model	20 to 80

6.9.2 Temperature and humidity (TH)

6.9.2.1 General

The objective of this AST is to evaluate the performance of the optical material under stress due to moisture and temperature. The Peck model is one of the models that can be used for accelerated testing, see B.7.

6.9.2.2 Model parameters

If the parameters of the Peck model (E_a, q) are available then this model may be applied over the validated range of conditions for relative humidity and temperature ($RH_\mathrm{min} \leq RH \leq RH_\mathrm{max}$ and $T_\mathrm{min} \leq T \leq T_\mathrm{max}$). The activation energy E_a and humidity exponent q are determined by experimental testing. The analysis obtaining E_a and q is outside the scope of this Technical Specification. If these parameters are not available, this model cannot be applied and testing for the full validation time of the product or component is required.

NOTE The model parameters could come from the component supplier.

6.9.2.3 Application variables

The application variables for the Peck model are the temperature T and the relative humidity RH. T_stress1 and RH_stress1 are the anticipated maximum application values for the in use component conditions. T_stress2 and RH_stress2 are the test values used in the accelerated stress test. Application and test stress levels shall be selected within the validated range: $RH_\mathrm{min} \leq RH_\mathrm{stress1} < RH_\mathrm{stress2} \leq RH_\mathrm{max}$ and $T_\mathrm{min} \leq T_\mathrm{stress1} < T_\mathrm{stress2} \leq T_\mathrm{max}$.

The acceleration factor is calculated by applying Equation (B.7) with the model parameters mentioned in 6.9.2.2 and application variables mentioned in 6.9.2.3. The reduced testing time is calculated by the desired component validation time, for example 6000 h or 25 % of rated life of the product, divided by the acceleration factor. The testing time, t_test, shall be the greater of the calculated reduced test time or 1000 h.

6.9.2.4 TH accelerated stress test

The test procedure is to subject the samples to T_stress2 and at RH_stress2 for t_test hours.

6.9.2.5 Compliance criteria

Compliance is checked by applying the failure criteria of 6.7 to the test results obtained from the pre- and post-stress tests according to 6.6.

6.9.3 Temperature and light exposure (TL)

The objective of this AST is to evaluate the performance of the optical material under stress due to temperature and exposure to light. The following test conditions apply:

- Irradiation with wave length: 445 nm (±5 nm) from a source whose infrared component has been filtered out. Alternatively excitation wavelength in application ±5 nm.
- Irradiance level: maximum irradiance level in application of the product declared by the manufacturer sets the test level as follows. The test irradiance shall be twice the maximum application irradiance. This is typically between 350 mW/cm^2 to 1000 mW/cm^2. The irradiance level shall be measured before starting the test and recorded in the principal component test report (Annex F).
- Duration: 1000 h.
- Maximum application temperature of the product declared by the manufacturer sets the test temperature as follows. The test temperature shall be the temperature of the component when operating at the maximum application temperature plus 20 °C.

The optical materials can be exposed to light via either of the following two set-ups:

- Using a standard temperature-controlled cabinet with an optical window to supply the light exposure. The optical window should be chosen such that it does not change the intensity and wavelength of the light exposure. The wavelength distribution and intensity shall be measured after the light has passed the window.
- Using a temperature-controlled hotplate for the optical material samples and the light exposed to it from the top, either with or without a lens or diffuser system.

Compliance is checked by applying the failure criteria of 6.7 to the test results obtained from the pre- and post-stress tests according to 6.4 and 6.6.

6.10 Light-transmitting materials

For light-transmitting materials, a preconditioning shall be performed according to J-STD-020E with 85 °C and 85 % relative humidity conditions.

After preconditioning, the AST of 6.9.2 and 6.9.3 shall be conducted.

Compliance is checked by applying the failure criteria of 6.7 to the test results obtained from the pre- and post-stress tests according to 6.6.

6.11 Light-reflecting materials

6.11.1 Dichroic-coated glass and aluminium-coated glass

For dichroic-coated glass and aluminium-coated glass the IQT of 6.8.1, 6.8.2, 6.8.3 and 6.8.4 shall be conducted.

In order to judge the durability of the coating, the samples shall be subjected to the adhesion test according to 6.5 after each IQT as specified in 6.8. Press the adhesive surface of the tape firmly against the coated surface and quickly remove it at an angle normal to the coated surface.

Compliance is checked by applying the failure criteria of 6.7 to the test results obtained from the pre- and post-stress tests according to 6.6.

6.11.2 Aluminium-coated plastic

For aluminium-coated plastics a preconditioning shall be performed according to J-STD-020E with 40 °C and 93 % relative humidity conditions.

After the preconditioning the AST of 6.9.2 shall be conducted.

To judge the durability of the coating, the samples shall be subjected to the adhesion test according to 6.5.

Compliance is checked by applying the failure criteria of 6.7 to the test results obtained from the pre- and post-stress tests according to 6.6.

6.11.3 White plastic/non-coated plastic

For white (non-coated) plastics, a preconditioning shall be performed according to J-STD-20E with 85 °C and 85 % relative humidity conditions.

After the preconditioning, the AST of 6.9.2 and 6.9.3 shall be conducted.

Compliance is checked by applying the failure criteria of 6.7 to the test results obtained from the pre- and post-stress tests according to 6.6.

6.12 Optical converters

Optical converters consist either of a phosphor layer deposited onto carrier material, or of phosphor particles dispersed within the bulk of a carrier material, or a colour filter. The carrier material can either be plastic compounds (e. g. polycarbonate or silicone) or a type of glass or ceramic.

In the case of a plastic compound carrier, with or without phosphor layer, the optical material can be regarded as a light-transmitting material and the qualification tests as denoted in 6.10 apply.

In the case of a glass carrier, the optical material can be regarded as a dichroic-coated material. The tests according to 6.9.2 and 6.9.3 shall be performed and in both cases followed by a scratch test according to ASTM D7027.

Compliance is checked by applying the failure criteria of 6.7 to the test results obtained from the pre- and post-stress tests according to 6.6.

7 Electronic subassemblies

7.1 General

The purpose of Clause 7 is to determine that the electronic subassembly is capable of passing the specified stress tests, and thus can be expected to give a certain level of reliability in general lighting applications.

Main stressors for electronic equipment are: temperature, mains voltage variations and humidity. Subclauses 7.7 and 7.8 specify a set of qualification tests that shall be considered:

- when a new circuit design is selected;
- when a new supplier is selected;
- when in an existing circuit design the following is changed:
  - a component;
  - a small adaptation of the PCB layout;
  - the interconnect technology (be it process, material and/or mechanical).

Where appropriate family qualifications can be done, according to:

- same topology or circuit layout;
- same component set or component family.

The qualification flowchart is depicted in Figure D.3.

7.2 Sampling requirements

Unless otherwise specified, a minimum of 30 electronic subassemblies per test shall be used. In order to include the effects of component variation, the sample set shall be evenly selected from at least three different component batches when such exist. For example, if a 30-sample set is selected, then 10 samples from each of three different component batches would be selected. For family qualification, the units shall be selected to represent the whole variety of the qualification family.

7.3 Production requirements

All electronic subassemblies for qualification purposes shall be produced on tooling and processes at the manufacturing site that will be used to support electronic subassembly deliveries at projected production volumes. Deviations shall be reported in the principal component test report (Annex F).

7.4 Pre- and post-stress electrical requirements

The electrical values below shall be measured at the test conditions as specified in the product specification before and after stress testing. Intermediate measurements (read points) might be useful. All electronic subassemblies used for qualification shall meet the product specification parameters before testing:

- product input and output power;
- product output voltage and current;
- power factor and harmonic distortion of the mains current input;
- relevant output current parameters for example ripple current or peak current.

7.5 Pre- and post-stress visual inspection

The construction, marking and finishing of the electronic subassemblies should be inspected prior to and after the qualification tests in order to judge the visual state of the units.

7.6 Failure criteria

This principal component is considered to have failed if any of the following criteria applies for each item in the test.

- Any deviation from rated electrical parameters compared to 0 h values, in particular:
  - any deviations in power factor by more than 15 %;
  - any deviations in the harmonic distortion of the current mains input by more than 15 %.
- The electronic subassembly exhibits any externally visible evidence of external cracks, mechanical damage and/or corrosion.

There are components in electronic subassemblies that cannot operate without failure in high temperatures or humidity. These types of failures will no longer follow an acceleration model. They will in fact be special cause failures for which no acceleration can be calculated.

Physical analysis (PA) should be performed for electronic subassemblies according to Clause E.4 on all units after completion of all tests. The post-electrical test of all samples shall be executed before any destructive physical analysis.

It is recommended that failures found during the qualification test be fully investigated until the root cause is found.

7.7 Initial qualification tests

7.7.1 Temperature and operation stress (PTC)

The objective of this IQT is to verify that the product will operate for a specified number of cycles under powered conditions in a temperature cycling environment. The test is referred to as power thermal cycling (PTC) and includes fast power cycling of the electronic subassembly. The test shall be conducted according to 15.2 of IEC 60929:2011; the following modified test conditions apply.

- Temperature cycling range: −20 °C to the highest specified temperature with a minimum of 50 °C with $\mathrm{d}T/\mathrm{d}t$ > 10 K/min. The temperature refers to the ambient temperature (t_{amb}) in the test cabinet.
- Powered: yes, test voltage is rated voltage ±10 %.

Compliance is checked by applying the failure criteria of 7.6 to the test results obtained from the pre- and post-stress tests according to 7.4 and 7.5.

7.7.2 Humidity and operation stress (HOT)

The objective of this IQT is to verify that the product will operate for a specified time under powered conditions in a humidity environment. The test is referred to as high humidity operation (HOT), with no cycling. The humidity conditions shall be conducted according to JESD22-A113F; the following general test conditions apply:

- duration: 250 h;
- humidity condition: 85 % relative humidity at 85 °C;
- powered: yes, test voltage is rated voltage ±10 %.

Compliance is checked by applying the failure criteria of 7.6 to the test results obtained from the pre- and post-stress tests according to 7.4 and 7.5.

7.8 Accelerated stress tests

7.8.1 Prediction models

Prediction models are needed to project the accelerated test conditions to the application profiles (Annex A). Some of the available acceleration models are described in Annex B. Table 4 maps the qualification test for electronic subassemblies with suitable models from Annex B for this test.

For electronic subassemblies it is common to calculate overall failure in time (FIT) rate numbers based on:

- tables of operating and/or non-operating constant failure rate values arranged by part type;
- multiplicative factors for different environmental parameters to calculate the operating or non-operative constant failure rate;
- multiplicative factors that are applied to a base operating constant failure rate to obtain non-operating constant failure rate.

This process is well described in several standards, among which are IPC-9592B and Telcordia Technologies SR-332. Being a pure add up of component FIT rates, the acceleration tests in 7.8.2 serve as an experimental check. The overall electronic subassembly FIT rate shall be supplied based on the combination of either of the two predictive methods and the experimental results.

Table 4 – Mapping the electronic subassembly qualification tests to the useable acceleration model with typical range of the acceleration factor

Qualification test	Acceleration model	Typical range of acceleration factor
Temperature, humidity and operation stress	Generalized Eyring model or Norris-Landzberg model	20 to 60

7.8.2 Temperature, humidity and operation stress (sequential ALT)

The objective of this ALT is to verify that the electronic subassembly will operate for a specified lifetime under powered conditions in a cyclic temperature and humidity environment. The test is referred to as accelerated life test (ALT). In an ALT, the power, temperature and humidity conditions may vary according to:

- power: 180 min on and 20 min off for a 200 min cycle;

- humidity: between 20 % relative humidity and 85 % relative humidity;
- temperature: between 0 °C and 100 °C.

Depending on the acceleration factor (Annex B and 7.8.1), one shall use the ALT profile that matches the product and application being tested. An example profile is listed in Table 5. The acceleration factor for this ALT profile can be calculated using the Norris-Landzberg model (Annex B). It is preferable that several ALT profiles are used in order to qualify the electronic subassemblies.

Compliance is checked by applying the failure criteria of 7.6 to the test results obtained from the pre- and post-stress tests according to 7.4 and 7.5.

Table 5 – Example ALT profile for an electronic subassembly

Segment	**Segment time** min	**Total time** min	**Temperature** °C	**Relative humidity** %
Start	0	0	0	40
1	30	30	85	40
2	15	45	85	85
3	570	615	85	85
4	15	630	85	40
5	30	660	30	40
6	60	720	30	40

8 Active and passive cooling systems

8.1 General

The purpose of Clause 8 is to determine that a cooling system is capable of passing the specified stress tests, and thus can be expected to give a certain level of reliability in general lighting applications. Cooling systems in lighting applications can be either passive or active. Passive cooling systems transport heat through natural physical means of conduction, convection (buoyancy) and/or radiation without application of a separate power source or active elements.

Examples are thermal interface materials (TIM, such as pastes, phase-change materials, potting materials), heat sinks from different materials (aluminium, copper, thermo-conductive plastics, heat-pipes), different finishing (material painting, surface finish), solder joints on PCBs and different substrates.

Active cooling systems use a power source or active element to increase the heat transfer rate, often by increasing mass flow or air velocity or raising temperature gradients. Active systems can be divided further into the following three categories:

- forced air or fluid circulation (e.g. fans, pumps);
- two-phase cooling system (e.g. air-conditioning);
- thermoelectric cooling (e.g. Peltier elements/heat pumps).

Excluded from this principal component are the LED package solder joints on PCBs. They are part of Clause 5 (LED package and interconnects). Main stressors and their effects on cooling systems are noted in Table 6. The most common effect is the degradation of the cooling performance due to several causes, such as material degradation, cracks, or delamination and/or loss of rotational speed. Thus, it is vital that this degradation is captured by the acceleration tests. Commonly used passive cooling systems make use of thermal interface materials. More advanced cooling systems are systems with pulsated air-jet technology and air-cooled fans. Acceleration tests for passive cooling systems should focus on the increase of the thermal interface resistance. Acceleration tests for active cooling systems should focus on the degradation of performance parameters such as rotational speed. Subclauses 8.9 and 8.10 specify a set of qualification tests that shall be considered for new cooling systems. Where appropriate, family qualifications can be done according to:

- same passive cooling type of material but different geometry (size or thickness);
- same active cooling technology but different performance.

Care should be taken to ensure that thermal stress introduced by the cooling system does not cause the product to fail.

The qualification flowchart is depicted in Figure D.4.

Table 6 – Examples of stressors, affected part of the cooling systems and its reliability effect.

Stressors	Which part of the cooling system is affected?	What is the effect?
Temperature	TIM, potting, Peltier element, pulsated air-jets, fan, heat pipe, thermoplastics	– Change in material characteristics (R_{Θ} change) – Fan used on high temperature causes an increase in noise level – In general, mechanical fractures, cracks, thermal tension, degradation of interface contacts, delamination, etc. can be observed – Outgassing and /or other chemical reactions – TIM degradation resulting in lower material properties – Degradation of bearings and electronics
Humidity	TIM, potting, thermoplastics, fans, pulsated air-jets	Absorption of moisture that results in change of material characteristics, delamination, corrosion
Light radiation	Thermoplastics, substrates	Change in material characteristics (cracks, delamination, brittleness)
Dust accumulation	Fans, pulsated air jets, heatsink fins	Cooling performance degrades, noise impact for fans
Vibration	All	Cooling performance degrades
Electrical stress (voltage spikes, line interruptions, supply voltage changes, overvoltages)	All	Cooling performance degrades, overvoltage may overstress TIM material
Chemical (salty atmosphere, salt water, sulphides, chlorines, etc.)	All except closed systems, special material finishes	Excessive corrosion

8.2 Cooling system test samples

Cooling system test samples should be taken if representative of the actual application. All qualification cooling samples shall be produced on tooling and processes that will eventually be used to manufacture the LED product. Deviations shall be reported in the principal component test report (Annex F).

When analysing a passive cooling component like a TIM, the PCB with LEDs should be mounted to a heatsink with the chosen TIM material in between. A thermocouple should be attached underneath the TIM on the top side of the heatsink plate in order to measure the degradation of the material. For passive cooling components like TIMs, any PCB size or LED count may be used but this shall be reported in the principal component test report (Annex F). A minimum of three samples of size 500 mm^2 shall be used for each qualification test.

When analysing an active cooling system like a pulsated air jet or a fan, the cooling system itself may be degraded separately (e. g. by placing it into a dust chamber) but the thermal effect of this degradation shall be analysed on the LED product. The change in performance parameters may be measured on the tested unit itself. A minimum of 20 active cooling samples shall be used for each qualification test.

8.3 Moisture preconditioning

Moisture preconditioning shall be executed according to JESD22-A113F. The initial thermal resistance (for passive cooling systems) or performance parameter (for active cooling systems) tests specified in 8.4 and 8.5 shall be executed before and after the moisture preconditioning.

8.4 Thermal resistance test

The thermal resistance of passive cooling components shall be tested according to ASTM D5470. The resulting R_{Θ} shall be reported in the principal component test report, Annex F.

8.5 Performance parameter test

For active cooling systems using air movement, the performance parameters shall be tested according to IPC-9591.

For active cooling systems using liquids, the performance parameters shall be tested according to the guidelines from the manufacturer.

8.6 Pre- and post-stress cooling performance requirements

Thermal resistance and performance parameters of the cooling system shall be measured before and after stress testing. Intermediate measurements (read points) might be useful. All tested units used for qualification shall meet the product specification parameters before testing. All tested units shall be tested for deviations in the following ways from the rated performance specification prior to and after the qualification tests:

- cooling performance;
- acoustic emissions;
- power consumption.

8.7 Pre- and post-stress visual inspection

The construction, marking and finishing of the cooling units should be inspected prior to and after the qualification tests in order to judge the visual state of the units.

8.8 Failure criteria

This principal component is considered to have failed if any of the following criteria applies for each item in the test.

- Loss of cooling performance over 10 %.
- Noticeably increased acoustic emissions, more than 3 dB.
- Power consumption exceeding the initial measured value by more than 20 %.
- The cooling unit exhibits externally visible physical damage (cracks, deformations) due to the qualification test.
- The thermal interface exhibits an interface delaminated surface area larger than 25 % of the total interface area.
- The cooling unit exhibits externally visible signs of corrosion due to the qualification test.

- Visible leakage of cooling liquids such as oil, grease and/or water.

An active cooling system, such as a pulsated air-jet or a fan, may be degraded separately (e.g. by placing it into a dust chamber), but the thermal effect of this degradation shall be analysed on the LED product.

It is recommended that failures found during the qualification test be fully investigated until the root cause is found.

Physical analysis (PA) should be performed for the tested units according to Annex E on all units after completion of all tests. The post thermal and performance parameter tests according to 8.4 and 8.5 respectively shall be executed before any destructive physical analysis.

8.9 Initial qualification tests

8.9.1 General

Qualification tests for cooling systems address the following stressors (see Table 6).

a) Elevated temperature in the temperature life test (TLT) specified in 8.10.3. For each specific cooling technique, the maximum and minimum allowable temperature is different and should be taken into account. This test mainly applies to cooling systems like potting, Peltier elements, pulsated air jet, fans, heat pipes and thermoplastics.
b) Cyclic temperature in the power temperature cycling test (CT) specified in 8.10.2. For each specific cooling technique the maximum and minimum allowable temperature and the allowable cycling time is different and should be taken into account.
c) Exposure to moisture, which is taken as a preconditioning step prior to the power temperature cycling test (CT).
d) Exposure to light (TL). This mainly holds for thermoplastics and the test as described under 6.9.3 (temperature and light exposure) applies.
e) Exposure to dust particles, in the dust test specified in 8.9.2. This test only applies to active cooling components such as fans, pulsated air jets and passive cooling components such as heatsink fins.
f) Exposure to vibration stress. During normal operation, as well as in shipping, active cooling systems such as fans and pulsated air jets may experience mechanical vibration. Verification of vibration stress shall be carried out according to IEC 60068-2-27. It is not further described in Clause 8.
g) Exposure to electrical stress, which can be captured by powering the units as is prescribed in the power temperature cycling test of 8.10.2.
h) Exposure to chemical stress. Testing in chemical environments is part of the verification on a system level, see Clause 10. It is not further described in Clause 8.

8.9.2 Dust

The objective of this IQT is to evaluate the performance of the active cooling system when subjected to dust particles. Since dust and contamination heavily affect the reliability of cooling products, including fans, the units should be tested in harsh dust environments. Dust testing shall be conducted according to IP5X in IEC 60529. The following test conditions apply:

- dust type: talcum powder;
- particle size: <□70 µm; ideally distributed within 1 µm to 10 µm;
- duration: 8 h;
- operating condition: continuous on.

Test to be executed in a dust chamber according to IEC 60529.

Compliance is checked by applying the failure criteria of 8.8 to the test results obtained from the pre- and post-stress tests according to 8.6 and 8.7.

8.10 Accelerated stress tests

8.10.1 General

Prediction models are needed to project the accelerated test conditions to the application profiles (Annex A). Some of the available acceleration models are described in Annex B. Table 7 maps the qualification tests for cooling systems with suitable models from Annex B for these tests.

Table 7 – Mapping the cooling system qualification tests to the useable acceleration model with typical range of the acceleration factor

Qualification test	Acceleration model	Typical range of acceleration factor
Temperature life test (TLT) Passive	Arrhenius	2 to 10
Temperature life test (TLT) Active	IPC 9591	1,5× per 10 °C temperature increase
Cyclic temperature test (CT) Passive	Coffin-Manson or Norris-Landzberg	5 to 15
Cyclic temperature test (CT) Active	Coffin-Manson or Norris-Landzberg or Inverse power law	5 to 20

8.10.2 Cyclic temperature test (CT) with humidity and with/without operational stress

The objective of this AST is to evaluate the performance of the cooling system in a cyclic temperature environment.

- Step 1: 168 h test at 85 °C and 85 % relative humidity (MSL1 conditions in JESD22-A113F MSL classifications).
- Step 2: 1 000 h (power) temperature cycling (number of cycles is under consideration). Temperature range strongly depends on the cooling technique.
  - For passive cooling (TIM, potting, thermoplastics): −40 °C to a maximum application temperature of the product declared by the manufacturer sets the test temperature as follows. The test temperature shall be the temperature of the component when operating at the maximum application temperature plus 20 °C.
  - For active cooling (fans, pulsated air-jets, Peltier elements): −40 °C to +85 °C, includes powering the cooling system. Maximize the power on/off cycles such as to obtain stable temperatures for at least 5 min.

Test shall be executed in standard cabinet/oven with controlled temperature.

Compliance is checked by applying the failure criteria of 8.8 to the test results obtained from the pre- and post-stress tests according to 8.6 and 8.7.

8.10.3 Temperature life test (TLT) passive cooling system

8.10.3.1 General

The objective of this AST is to evaluate the performance of the passive cooling material under stress due to temperature. The Arrhenius model is used for accelerated testing, see Clause B.2.

8.10.3.2 Model parameters

If the parameter of the Arrhenius model (E_a) is available then this model may be applied over the validated range of conditions for temperature ($T_{min} \leq T \leq T_{max}$). The activation energy E_a is generated by experimental testing outside the scope of this Technical Specification. If this parameter is not available, this model cannot be applied and testing for the full validation time of the product or component is required.

NOTE The model parameter (E_a) could come from the component supplier.

8.10.3.3 Application variables

The application variable for the Arrhenius model is the temperature T. $T_{stress1}$ is the anticipated maximum application value for the in use component condition. $T_{stress2}$ is the test value used in the accelerated stress test. Application and test stress level shall be selected within the validated range: $T_{min} \le T_{stress1} < T_{stress2} \le T_{max}$.

NOTE The model parameter T_{max} is set below the material phase change temperature.

The acceleration factor is calculated by applying the equation in Clause B.2 with the parameter and variables above. The reduced testing time is calculated by the desired component validation time, for example 6 000 h or 25 % of rated life of the product, divided by the acceleration factor. The testing time, t_{test}, shall be the greater of the calculated reduced test time or 1 000 h.

8.10.3.4 TLT accelerated stress test

The test procedure is to subject the samples to $T_{stress2}$ for t_{test} hours.

Compliance is checked by applying the failure criteria of 8.8 to the test results obtained from the pre- and post-stress tests according to 8.6 and 8.7.

8.10.4 Temperature life test (TLT) active cooling system

The objective of this AST is to evaluate the performance of the cooling system under high-temperature stress. The performance parameters shall be tested according to 8.5 with the following test conditions:

- duration: 2 000 h;
- temperature:
  - for active cooling, temperature is limited to $t \le 95$ °C, unless specified otherwise by the manufacturer;
  - for fans, temperature is limited to $t \le 75$ °C, unless specified otherwise by the manufacturer;
  - for pulsated air jets, temperature is limited to $t \le 85$ °C, unless specified otherwise by the manufacturer.

Compliance is checked by applying the failure criteria of 8.8 to the test results obtained from the pre- and post-stress tests according to 8.6 and 8.7.

9 Construction materials

9.1 General

The purpose of Clause 9 is to determine that the materials used to construct the mechanical system are capable of passing the specified stress levels and thus can be expected to give a certain level of reliability in general lighting applications.

The qualification flowchart is depicted in Figure D.5. The samples taken should be representative of the actual application. All qualification samples shall be produced on tooling and processes that will eventually be used to manufacture the LED products. Deviations shall be reported in the principal component test report (Annex F).

DPA or PA should be performed for mechanical units according to its associated category from Annex E, on all units after completion of all tests.

9.2 Mechanical components and interconnects

Categories of mechanical components and interconnects that can be found in an LED product include the following.

- Structural components
  - This category relates to parts outside of the LED product that are used to hold the components together. An example is the plastic housing. Qualification tests for these components can be found in the IEC lamp safety standards.
- Fasteners
  - A fastener is a component that mechanically joins or affixes two or more objects together. An example is an LED holder or, even simpler, a screw. Obviously there are many types and/or techniques to mechanically join two or more objects together. In an LED product, the main function of joining objects together is to obtain and maintain a certain level of thermal management. Therefore, thermal interface reliability is the object of testing under Clause 8 (cooling systems).
- Adhesives
  - Adhesives can either function as a thermal interface and/or a mechanical connection. In both cases, the adhesion durability is the object of testing under 8.10.2 (cyclic temperature test).
  - Outgassing of these materials can cause chemical interactions between or within LED products and impact their performance. Chemical effects on the LED package are to the object of testing under Clause 5 (LED packages and interconnects). Chemical interactions on a system level are the object of testing under 8.10.2 (cyclic temperature test).
- Sealing gaskets
  - Sealants are used to prevent the penetration of liquids, gas and/or dust from one location through a barrier into another. Sealants are limited to LED products for special applications, for example under-water swimming pool lamps. They can be regarded and tested as a thermal interface material and subjected to durability testing under 8.10.2, the cyclic temperature test (CT) with humidity, using the sealant capacity as the pre- and post-stress testing measure.
- Electrical terminals/wires
  - An electrical terminal[3] or wire is an electro-mechanical device for joining electrical circuits as an interface using a mechanical assembly. There are several standards that deal with these components:
    - IEC 61995 (all parts);
    - IEC 60811-508;
    - IEC 60811-509;
    - IEC 61249 (all parts).
  - The reliability of electrical terminals and wires are tested under Clause 7 (electronic subassemblies).

9.3 Mechanical interfaces between different components

Categories of mechanical interfaces that can be found in an LED product include the following.

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[3] Adapted from SOURCE: Power connector, Wikipedia: The Free Encyclopedia, with the permission of the author(s).

- Mechanical interfaces

  Mechanical interfaces are those interfaces that connect two different part of an LED product together, examples are (but not limited to):

  - LED emitter to substrate;
  - substrate to TIM;
  - TIM to heatsink;
  - substrate to controlgear;
  - controlgear to housing;
  - LED light source/lens to lamp;
  - cap to lamp.

  The interfaces mainly act on a system level and are subjected to testing under Clause 10 (final product).

- Electrical interfaces

  Electrical interfaces are interfaces through which an electrical current is driven. In an LED product, the main electrical interfaces are:

  - Soldered joints

    Soldered joints are used in several parts of the LED product. Those that are used in soldering the LED package to the printed circuit board are subjected to testing under Clause 5 (LED package and interconnects): temperature cycling (TMCL). Those that are used in soldering the electronic components to the printed circuit board are subjected to testing under 7.7.1(electronic subassemblies): Temperature and operation stress (PTC)

  - Cap-to-controlgear and controlgear-to-LED package connections

    The cap-to-controlgear and controlgear-to-LED package connections are tested under Clause 7 (electronic subassemblies).

- Thermal interface materials

  Thermal interface materials, also belonging to this group, are subject to testing under Clause 8 (cooling system).

9.4 Chemical interactions

Outgassing of materials in an LED product can cause chemical interaction that can lead to the following.

- Tarnish of silver-plated areas

  - Tarnish[4] is a thin layer of corrosion that forms over copper, brass, silver, aluminium, and other similar metals as their outermost layer undergoes a chemical reaction. LED packages with silver-plated lead frames can decrease its lighting performance and turn black (or tarnish) when exposed to substances such as sulphur, chlorine or other halogen compounds. Environmental tests for LED packages and interconnects shall be conducted according to 5.11.6.

- Degradation of luminous flux in LED products due to contamination of optical materials by volatile organic chemicals

  - This phenomenon occurs in physically closed systems, which means space without air movement. Within the LED product, the operation leads to elevated temperatures in the closed system causing volatile organic chemicals (VOCs) to vaporize and diffuse within the system. This diffusion of VOCs can affect normal operation in LED products by deposition onto the optical system components. VOCs can be generated from the

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[4] Adapted from SOURCE: Tarnish, Wikipedia: The Free Encyclopedia, with the permission of the author(s).

silicone encapsulant itself and other materials, such as glues (sealing material), label stock coatings, thermal pads, the O-ring and/or potting materials.

Outgassing of VOCs shall be tested according to ASTM E595.

Table 8 lists the chemicals that should not be used in LED products for general lighting applications.

Table 8 – List of undesired chemicals in LED products for general lighting.

Category	**Chemical name**
Solvents	Toluene, xylene, benzene, chloromethane, chloroform, ethyl acetate, butyl acetate, acetone, MEK, MIBK
Acid	HCl, H_2SO_4, HNO_3
Alkali	KOH, NaOH, LiOH, $Ca(OH)_2$
Oil	Diesel oil, petroleum, hydro carbons
Adhesives	Cyanoacrylates

10 Final product testing

10.1 General

The purpose of Clause 10 is to utilise the information from the component tests and apply it to the final products via knowledge of principal component reliability in the final assembly. It is understood that the assembly will have interactions between components and therefore is not necessarily representative of the full product performance, but gives guidance on the most vulnerable components.

Verification of the final product is based on a ‘test-to-pass’ principle (Clause C.3) to address possible early interactions between the principal components that were not addressed during the qualification tests for the principal components. The test-to-pass method to verify the final product is limited by the fact that deterioration curves for each component cannot be exactly determined. Different system reliability methods are explained in Annex C.

The verification tests for the final products can be done under accelerated stress conditions but are limited by the maximum allowable stresses according to all material specifications. Family qualifications can be done on the final product level, according to the same principal components used for the new product, provided that acceleration data for the principal components is available.

10.2 Principal component reliability in the final product

Principal components can influence several performance parameters in the LED product, see Table 9. Other key performance parameters not listed in Table 9 may exist that should be considered in the context of the principal components.

Table 9 – Influence of the principal components on the final product.

	Principal component				
Performance Parameter	**LED package and interconnects**	**Optical materials**	**Electronic subassemblies**	**Cooling Systems**	**Construction Materials**
Lumen depreciation	█	█	▒	▒	▒
Abrupt failures	█	░	█	█	█
Colour point shift	█	█	░	░	▒
Electrical deviations	░	░	█	░	█
Darker cells in Table 9 indicate a higher influence on the product performance parameters. For example, luminous flux depreciation in an LED product is strongly related to the luminous flux decay in the LED and the optical material, but less related to electrical deviations in the electronic subassembly (can lead to lower forward currents), degradation of the cooling system (can decrease efficiency of the LED packages), and the degradation in the mechanical principal component (can lead to reflectivity loss).					

10.3 Minimum validated AST time

With the known acceleration factors for the principal components and their associated validated AST time(s) the following steps are taken to qualify the final product.

- Step 1: Deduce the conditions of each principal component when operating in the application.
  - This involves maximum and minimum temperatures, humidity conditions, maximum power and other input parameters. Annex A lists the conditions for two example application profiles, but temperatures in the principal components shall be either measured or determined from thermal simulations. For example: measure or calculate the LED junction temperature (t_j), the maximum temperature of the optical system, and the electronic subassembly in an on-state for the LED product.
- Step 2: For each principal component calculate the acceleration factor.
  - This involves the use of the acceleration models and Table 1 (LED package and interconnects), Table 3 (optical materials), Table 4 (electronic subassemblies) and Table 7 (cooling systems). An example acceleration factor calculation for an optical material is depicted in Clause B.11. Imagine an LED product for indoor purposes. According to the application profile, the average relative humidity is 60 %. Thermal measurements show that the maximum temperature in the optical material is equal to 100 °C. Reading from Table B.2 this means that the AF = 6. Repeat this for each component and each possible stressor.
- Step 3: Calculate and list all the validated AST time(s) in a table.
  - This should be done for each principal component. The example in Table 10 comprises a system with a light transmitting plastic as an optical material, and a thermal interface material as the cooling component.

Table 10 – Example list of validated AST times.

Principal component	Validated AST time
LED package	–
LED package interconnects	Thermo-mechanical stress, TMCL: 4 000 h
Optical materials	Temperature and humidity stress, TH: 3 000 h Temperature and light exposure, TL: 6 000 h
Electronic subassemblies	Temperature, humidity and operation stress, seq. ALT: 10 000 h
Cooling systems	Temperature life test, TLT: 5 000 h Cyclic temperature test, CT: 7 500 h
Construction materials	–

10.4 Final product qualification for reliability

Final product qualification is the responsibility of the individual manufacturer. This Technical Specification provides a test regime to assist in this effort. By completing all of the relevant tests the principal components have been tested for reliability. The final product assembly should be tested with consideration of the information in Table 8 and Table 10. The final product testing should identify the effects of other components and interactions. Annex C may be used as guidance in developing a final product qualification plan.

Endurance tests to demonstrate basic robustness of final product are specified in the relevant product performance standards (e.g. IEC 62612, IEC 62717 and IEC 62722-2-1). The observations for these tests should be used together with the gathered component reliability data to guide the extent of further reliability testing of the final product as a complete assembly. Final products used for verification shall be produced on tooling and processes at the manufacturing site that will be used for product deliveries at projected production volumes.

11 Product updates

In case of requalification associated with a material, design and/or process change, a limited set of qualification tests should be considered. For any change, evidence shall be supplied that the change has no negative influence. A change in a principal component can be major or minor. In case of a major change, all qualification tests shall be performed. In case of a minor change, a limited set of tests, as decided by the manufacturer, shall be performed. A list of minor/major differences between the modified principal component(s) accompanies the principal component test report (Annex F).

Table 11 lists the changes that are considered to be minor or major for each principal component and for the final LED product.

Table 11 – Minor and major change list per principal component.

Principal component	Minor change	Major change
LED package and interconnects	Using the same part/material list with a: - different package footprint and/or dimension, - a slightly different (improved) process. Other manufacturing location Interconnect technology (process or material) Epoxy technology (process or material) Design changes (any thickness, size, tracks)	Part/material list Die technology (process or material)
Optical materials	Other additives Other manufacturing location Design changes (any thickness or size)	Process change Material change
electronic subassemblies	Component change with equal or better performance Small circuit (PCB) design adaptation	Circuit re-design Interconnect technology (process, material or mechanical)
Cooling systems	Design changes (any thickness or size) Performance changes (e.g. rotational speed, power)	Process change Material change Technology change
Construction materials	Same category with design change (any size) Same category with performance change Other manufacturing location	Process change Material change Category change
LED Product	Same principal component with t_p point below manufacturer specified value Other manufacturing location Small change in design	Per principal component: use of a new technology Significant change in design

Annex A
(informative)

Application profiles

The application profile describes the environmental loads (or stressors) that are imposed upon the product under normal operation conditions. In these conditions, LED products are subjected to the following identified loads:

- temperature: ambient temperatures differ per area in the world and significantly affect the reliability of LED products by degradation and elevated levels.
- humidity: humidity is known to ingress LED products and cause corrosive kind of failures.
- mechanical: static and dynamic forces (such as vibration) are imposed upon the LED product and can cause fatigue kind of failures.
- chemical: under harsh environment, as in outdoor, chemical substances can react with the principal components in the LED product.
- electrical: unstable mains can cause spikes that can damage the electrical components in the LED product.
- light intensity: UV-light from the sun and blue light from the LED can cause degradation of the optical component.

The profiles given in Table A.1 are examples. Other profiles may be developed depending on specific conditions of use for which the particular LED product is specified.

Table A.1 – Example of two application profiles

Application profiles for LED products			**Application area**	
Stressor	**Attribute**	**Unit**	**Profile 1**	**Profile 2**
Temperature	minimum	°C	−20	10
	maximum	°C	30 to 40 (off) 70 (on)	20 (off) 90 to100 (on)
	cycles/day	–	1	1 to 4
	number of operating	h/year	4 000 to 8 000	1 000 to 9 000
Relative Humidity	minimum	% relative humidity	30	30
	maximum	% relative humidity	90	60
	average	% relative humidity	60	45
Mechanical	shock amplitude (impact)	g, g_{rms}	30	
	shock number	–	2	
	vibration cycles	–	30	
	frequency	Hz	10 to 55	
Chemical	exposure	–	Sulphide, Hydrogen, Chloride,	Sulphide, Chloride
Electrical	average voltage	V	110 to 230	110 to 230
	range	V	110 to 277 (−6 %, +8 %)	110 to 277 (−6 %, +8 %)
	over voltage	%	−10 %, +10 %	−10 %, +10 %
Light	intensity	W/m^2	800	250

Annex B
(informative)

Acceleration models[5]

B.1 General

Accelerated tests are performed to accelerate a physical failure mechanism without inducing new failure mechanisms that do not exist in the application profile. Acceleration factors use time-to-fail at a particular accelerated stress level for a particular failure mechanism to predict the equivalent time to fail at the application profile field stress level. Under linear acceleration we define acceleration factor (AF) as:

$$AF = \frac{\text{Time to fail}(Stress1)}{\text{Time to fail}(Stress2)} \tag{B.1}$$

where

$Stress2 > Stress1$

Acceleration models are usually based on the science underlying a particular failure mechanism. Successful empirical models are close approximations of a number of complicated physics or kinetics models as to determine when the theory of the failure mechanism is eventually understood. Note that in the case of linear acceleration, while predicting time-to-fail for the application profile, the type of life distribution (Lognormal, Weibull, Exponential, etc.) and the slope parameters do not change but the location parameters change. In Subclauses B.2 to B.8, acceleration models for failure mechanisms accelerated by temperature, humidity, mechanical, electrical and chemical stressors are presented.

B.2 Arrhenius model

The Arrhenius model has been used successfully for many chemical and physical failure mechanisms (chemical reactions, diffusion processes or migration processes) accelerated by temperature. The acceleration factor is given by:

$$AF = \exp\left[\frac{E_a}{k_B}\left(\frac{1}{T_{stress1}} - \frac{1}{T_{stress2}}\right)\right] \tag{B.2}$$

where

E_a is the activation energy (eV);

k_B is a Boltzmann’s constant;

T is the temperature in K.

Note that the only empirical parameter in Equation (B.2) is the activation energy. By collecting data at multiple stress conditions, the activation energy for a specific failure mechanism can be estimated. Typical activation energy (E_a) values are in the range of 0,2 eV to 2,0 eV depending on the failure mechanism.

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[5] Adapted from *Solid mechanics and its applications*, with the permission of the author(s) (see Bibliography).

B.3 Eyring model

An extension of the Arrhenius model, Eyring's model may be used to describe the effect that temperature has on complex chemical reaction rates. The acceleration factor is given by:

$$AF = \left(\frac{T_{stress2}}{T_{stress1}}\right)^{m} \times AF_{Arrhenius} \tag{B.3}$$

where

T is the temperature in K;

m is the reaction dependent parameter;

$AF_{Arrhenius}$ is the Arrhenius acceleration according to Equation (B.2).

Values for the parameter m range from 0 to 1, with 0,33 as typical value.

B.4 Coffin-Manson model

A popular model used for thermal-cycling-related failures is the Coffin-Manson model. Thermal cycling causes thermal expansion and contraction within the product, which induce mechanical stresses. These changing mechanical stresses can eventually cause fatigue failures (cracks). Coffin-Manson in its simplest form takes into account the temperature changes within the product. The acceleration factor is given by:

$$AF = \left(\frac{\Delta T_{stress1}}{\Delta T_{stress2}}\right)^{-n} \tag{B.4}$$

where

ΔT is the entire temperature cycle range within which a device operates;

n is the material-dependent parameter.

Values for the parameter n range from 1 to 5, with 2,0 as typical value.

B.5 Norris-Landzberg model

The simple form of the Coffin-Manson equation doesn't account for the time-dependent effects. To account for the effect of these time-dependent properties (strain rate effects, stress relaxation, etc.) on fatigue life, Norris and Landzberg (IBM, 1969) introduced an empirical frequency factor into the original Coffin-Manson equation. The acceleration factor is given by:

$$AF = \left(\frac{\Delta T_{stress1}}{\Delta T_{stress2}}\right)^{-n} \left(\frac{f_{stress1}}{f_{stress2}}\right)^{o} \exp\left[\frac{E_a}{k_B}\left(\frac{1}{T_{stress1}} - \frac{1}{T_{stress2}}\right)\right] \tag{B.5}$$

where

ΔT is the entire temperature cycle range within which a device operates;

T is the temperature in K;

f is the frequency of applied thermal cycle stress;

n is the material-dependent parameter;

o is the frequency-dependent parameter;

E_a is the activation Energy (eV);

k_B is a Boltzmann's constant.

Values for the parameter o range from 0 to 1, with 0,33 as typical value.

B.6 (Inverse) power law

Increasing electrical stress (voltage or current) is a common method to accelerate failures in electrical materials and components. The (inverse) power law is frequently used to describe the effect that these electrical stresses have on reliability. The acceleration factor is given by:

$$AF = \left(\frac{ES_{stress2}}{ES_{stress1}} \right)^{-p} \tag{B.6}$$

where

ES is the electrical stress;

p is the electrical dependent parameter.

Inverse power law denotes $p > 0$, and power law $p < 0$. Thus, values for the parameter p range from −20 to 20 (zero is excluded).

B.7 Peck model

Corrosion induced by the moisture in the environment is one of the commonly seen failure mechanisms in electronics products. Humidity also is responsible for causing some of the interfacial delamination failures induced by hygro-thermal stresses. The acceleration model widely used to model the effect of relative humidity on failures is the Peck model. The acceleration factor is given by:

$$AF = \left(\frac{RH_{stress1}}{RH_{stress2}} \right)^{-q} \exp\left[\frac{E_a}{k_B} \left(\frac{1}{T_{stress1}} - \frac{1}{T_{stress2}} \right) \right] \tag{B.7}$$

where

RH is the relative humidity (%);

q is the humidity dependent parameter;

E_a is the activation energy (eV);

k_B is a Boltzmann's constant;

T is the temperature in K.

Values for the parameter q range from 0 to 3, with 2,5 as typical value.

B.8 Generalized Eyring model

Sometimes in addition to high temperature and relative humidity, another stress is also influential in driving failures. Examples are the combination of acceleration by temperature, humidity and voltage or light exposure. In these cases, the generalized Eyring model combines the Eyring model (read: Arrhenius model) with an added inverse power law term. The acceleration factor is given by:

$$AF = \left(\frac{L_{stress1}}{L_{stress2}}\right)^{-r} \left(\frac{RH_{stress1}}{RH_{stress2}}\right)^{-q} \exp\left[\frac{E_a}{k_B}\left(\frac{1}{T_{stress1}} - \frac{1}{T_{stress2}}\right)\right] \quad (B.8)$$

where

r is the added stress dependent parameter;

L is the added stress level;

RH is the relative humidity (%);

q is the humidity dependent parameter;

E_a is the activation energy (eV);

k_B is a Boltzmann's constant;

T is the temperature in K.

Values for the parameter r can range from −10 to 10 (zero is excluded).

B.9 Sample size calculation[6]

There are many different ways to determine the sample size for an accelerated test. The sample size is an important feature of any test in which the goal is to make inferences about a population from a sample. In practice, the sample size used in a reliability test is determined based on the expense of data collection, and the need to have sufficient statistical power. A choice of small sample sizes, though sometimes necessary, can result in low confidence levels, wide confidence intervals or risks of errors in statistical hypothesis testing.

When using accelerated testing the sample size, assuming an exponential distribution, can be calculated using:

$$n = \left(\frac{L}{T \times AF}\right) \times \left(\frac{\ln(1 - CL)}{\ln(R)}\right) \quad (B.9)$$

where:

L is the specified product life in h;

T is the total test time in h;

AF is the acceleration factor;

CL is the confidence level ($0 < CL < 1$);

R is the reliability level ($0 < R < 1$).

Depending on the confidence and reliability level, the sample size may vary significantly. Assuming that $L = T \times AF$ so that the first term equals to 1, Table B.1 lists the value of the second term as a function of the confidence and reliability level.

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[6] Adapted from *Sample size determination*, Wikipedia: The Free Encyclopedia, with the permission of the author(s).

Table B.1 – Sample sizes versus confidence and reliability level assuming $L = T \times AF$

	Reliability level (R)					
Confidence level (CL)	0,6	0,7	0,8	0,9	0,95	0,99
0,6	2	3	4	9	18	91
0,7	2	3	5	11	23	120
0,8	3	5	7	15	31	160
0,9	5	6	10	22	45	229
0,95	6	8	13	28	58	298
0,99	9	13	21	44	90	458

B.10 Basic guidelines[7]

Some guidelines for the use of acceleration models include the following.

- Acceleration tests shall generate the same failure mode occurring in the field. Generally, accelerated tests are used to obtain information about one particular, relatively simple failure mechanism (or corresponding degradation measure). If there is more than one failure mode, it is possible that the different failure mechanisms will be accelerated at different rates. Then, unless this is accounted for in the modelling and analysis, estimates could be seriously incorrect when extrapolating to lower use-levels of the accelerating variables.
- Accelerating variables should be chosen to correspond with variables that cause actual failures.
- With controlled changes in the principal components, the acceleration parameters may not change significantly. Only one verification test is required for identical acceleration parameters.
- Accelerated tests should be designed, as much as possible, to minimize the amount of extrapolation required. High levels of accelerating variables can cause extraneous failure modes that would never occur at use-levels of the accelerating variables. If extraneous failures are not recognized and properly handled, they can lead to seriously incorrect conclusions. Also, the relationship may not be accurate enough over a wide range of acceleration.
- Accelerated test programs should be planned and conducted by teams including individuals knowledgeable about the product and its use environment, the physical, chemical or mechanical aspects of the failure mode, and the statistical aspects of the design and analysis of reliability experiments.

B.11 Example

Assume the release of a plastic material that has its melting point at 140 °C. The product will be used in an indoor and outdoor environment. A set of acceleration tests are conducted with the following conditions:

- three relative humidity values, with RH_{test} = 30 %, 60 % and 90 %;
- three temperatures with t_{test} = 100 °C, 110 °C and 120 °C.

For these stressors, the Peck model in B.7 can be used. The test pass/fail criterion is: maximum of 10 % reduction in transparency (compared to 0 h value). Using the test results, the parameters q and E_a can be deduced and are calculated to be:

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[7] Adapted from *A Review of Accelerated Test Models*, with the permission of the author(s) (see Bibliography).

- q = 2;
- E_a = 0,6 eV.

AF calculations are done for user temperatures in the range of 70 °C (outdoor) to 100 °C (indoor) and a relative humidity of 45 % (average indoor) and 60 % (average outdoor). The results are listed in Table B.2.

Table B.2 – Example of calculated acceleration factors

	t_{use} (°C)			
RH_{use} (%)	**70**	**80**	**90**	**100**
45	53	30	17	10
50	43	24	14	8
55	35	20	12	7
60	30	17	10	6

Annex C
(informative)

System reliability[8]

C.1 General

Many textbooks are available that describe reliability principles, ranging from its history, (accelerated) testing, system reliability, reliability predictions to reliability standards. It is not the intention to repeat and/or summarize this extensive number of published pages in Annex C. In this annex, only the basic principles and those detailed reliability theories that are important for LED products are discussed.

C.2 Basic principles

A system is a collection of components, subsystems and/or assemblies arranged to a specific design in order to achieve desired functions with acceptable performance and reliability. The types of components, their quantities, their qualities and the manner in which they are arranged within the system have a direct effect on the system's reliability. Often, the relationship between a system and its components is misunderstood or oversimplified.

From a system reliability point of view, the challenge is to master the reliability of its components. Clearly, each system, whatever the complexity, can only last as long as its lowest-life component. The reliability may be measured in different ways depending on the particular situation, examples are:

- MTTF;
- number of failures per time unit (failure rate or field call rate);
- the probability that the item does not fail in a time interval (0, t) (survival probability);
- the probability that the item is able to function at time t (availability at time t).

If the item is not repaired after failure, the third and fourth situations coincide. For precise mathematical definitions, refer to the text books listed in the Bibliography.

Whatever the complexity of the system, its reliability is determined by its components and the interaction between them. The overall system reliability is a combination of all failure modes in each component. With the given application profile, one can calculate the reliability performance of the system. Note that investigations into the physics of failure are needed to understand the failure modes, combined with any sort of testing. Verification testing is needed on a product level.

C.3 Testing on the system level

To cover system reliability, one would need to test the reliability performance of both the components and the total system. If the total system is aimed for long lifetimes, which is the case for LED products, a common way of tackling this requirement is to expose the device to sufficient overstress to bring the time to failure to an acceptable level. Thereafter, one tries to “extrapolate”, from the information obtained under overstress, to normal use conditions. Depending on the kind of device in question, the accelerated testing conditions may involve a higher level of temperature, pressure, voltage, load, vibration, and so on, than the corresponding levels occurring in normal use conditions. These variables are called stressors.

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[8] Adapted from *Solid State Lighting Reliability*, with the permission of the author(s) (see Bibliography).

This approach is called accelerated life testing (ALT) or overstress testing. There are basically two different reliability test approaches:

- Test-to-pass

  Test-to-pass, demonstration testing or zero failure acceptance testing is an approach in which a certain number of test cycles are needed without the occurrence of failures. Test to pass only provides pass-fail results; the results do not give any information with respect to the reliability as a function of time (or kilometres or cycles). These limitations are addressed by test to failure.

- Test-to-failure

  Test-to-failure is an approach in which the tests are continued until at least 65 % of the population failed. This approach will give more information on failure modes, but the limitation could be long duration of the test.

For the principal components in an LED product, it is advised to follow a test-to-fail approach, preferably using meaningful accelerated tests. For LED products as a system, a test-to-pass approach is advised. Some generic rules for that are:

- each principal component in a system exhibits its own failure modes that needs to be captured by:
  - experiments using at least three accelerated testing conditions;
  - numerical/analytical models that describe the reliability physics or physics of failure (see Annex B).
- interactions between the components shall be captured by:
  - testing the total system;
  - slightly accelerating environmental user conditions in a physically correct manner.

In most industries, standard tests are used in order to quantify the reliability performance of the components and systems. Examples are the MIL standards for the military and the JEDEC standards for electronics.

C.4 System reliability prediction

C.4.1 General

In system reliability, one will always have to work with models of the system. In practical situations, the analyst will have to derive (stochastic) models of the system at hand, or at least have to choose from several possible models before an analysis can be performed. To be “realistic”, the models shall describe the essential features of the system, but do not necessarily have to be exact in all details. Always bear in mind that one is working with an idealized, simplified model of the system. Traditional handbook-based reliability prediction methods for electronic products include MIL-HDBK-217, Telcordia SR-332 (formerly Bellcore), PRISM, FIDES and the Chinese GJB299B. These methods rely on analysis of failure data collected from the field and assume that the components of a system have inherent constant failure rates that are derived from the collected data.

Much literature is available on the prediction of system reliability; it is not the intention to summarize or to repeat this information. Annex C only lists those techniques that can be applied for system reliability prediction of LED products.

C.4.2 Block diagrams

Reliability block diagrams are described as a means to represent the logical system architecture and create system reliability models. Possible logical structures are serial, parallel and/or combinations of these two. In a serial structure with n independent components, the system reliability is calculated as the multiplication of the individuals, as shown in Equation (C.1):

$$R_{total} = \prod_{i=1}^{n} R_i \tag{C.1}$$

Consider a series structure of four independent components. At a specified point of time, the component reliabilities are R_1 = R_2 = 0,99, R_3 = 0,97, and R_4 = 0,94. The system reliability at time t is then equal to 0,99 × 0,99 × 0,97 × 0,94 = 0,89. In a serial system, the product is at most as reliable as the least reliable component. In a parallel structure with n independent components; the system reliability is calculated as shown in Equation (C.2):

$$R_{total} = 1 - \prod_{i=1}^{n} (1 - R_i) \tag{C.2}$$

Consider a parallel structure of four independent components. At a specified point of time, the component reliabilities are R_1 = R_2 = 0,99, R_3 = 0,97, and R_4 = 0,94. The system reliability at time t is then equal to 1 − (1 − 0,99) × (1 − 0,99) × (1 − 0,97) × (1 − 0,94) = 0,999. So, parallel systems are in principle more reliable than serial systems.

LED products are comprised of a combination of serial and parallel structures (or components). It makes the structure functions more complex. The complexity increases even more when redundancy is present, when product repair is an option, and/or when interactions play a dominant role (meaning that the assumptions of independency disappear). In such cases, it becomes inevitable to use dedicated software to determine the structural diagram of the system and calculate its reliability.

C.4.3 Fault tree

Fault-tree analysis (FTA) is a deductive methodology to determine the potential causes of failures and to estimate the failure probabilities (IEC 61025). Fault-tree analysis addresses system design aspects and potential failures, tracks down system failures deductively, describes system functions and behaviours graphically, focuses on one error at a time, and provides qualitative and quantitative reliability analyses. The purpose of a fault tree is to show the sets of events – particularly the primary failures – that will cause the top event in a system. In an FTA, standard symbols to denote so-called events and gates are used to calculate the failure probability of the system.

C.4.4 Markov chains

A Markov chain is a stochastic process that describes transitions in time between discrete numbers of states (see IEC 61165). Markov chains, named after Andrey Markov, are a mathematical system that undergoes transitions from one state to another, between a finite or countable number of possible states. Markov chains describe the failure distribution change by time. Monte Carlo simulations often go hand in hand with Markov chains in order to update the state of the system (read: failure probability) at a certain time. The changes of state of the system are called transitions, and the probabilities associated with various state-changes are called transition probabilities. Theoretically, when the system has n components, and each component has two states (functioning and failed), the system will have at most $2n$ different states.

C.4.5 Bayesian networks

Large systems become difficult to model with Markov chains because they induce a combinatory explosion of states. Fault trees are also difficult to implement in large systems and particularly if the studied system presents redundant failures. In this context, Bayesian networks (BN) is a very interesting methodology. They allow the stochastic modelling of reliability in a compact and graphic form. The graphical form commonly used for BN is the directed acyclic graphs (DAGs) whose nodes represent random variables and whose arcs represent direct influences between adjacent nodes. Modelling with a BN is realized with a single ‘V structure’ in which the conditional probability table contains the failure propagation mechanisms through the functional architecture of the system. BNs build the relationships between the nodes and calculate the nodal influence by such relationships. The influences represented by the arc of a Bayesian networks can be probabilistic or deterministic.

C.4.6 Chi-square[9]

The Chi-square distribution can be used to find the confidence intervals on the failure rate and the MTTF of the exponential distributions. The distribution can also be applied to the Weibull distribution when the shape parameter (β) is known (so called WeiBayes method). This feature focuses on confidence intervals when the underlying failure distribution is exponential. The estimate for failure rate (λ) is calculated as the ratio of the number of failures to the total testing time. Alternatively, the estimate of MTTF is calculated as the ratio of the total testing time to the number of failures. If no failures are observed during a test on n units over a duration of time t, then based on confidence levels, the upper bound of the failure rate can be calculated as shown in Equation (C.3):

$$\lambda_{\text{upperbound}} = \frac{\chi^2_{\text{confidencelevel}}}{n \times t} \tag{C.3}$$

where:

$\lambda_{\text{upperbound}}$	is the upper value for the failure rate;
χ	is the Chi-square value at a given confidence level, equal to 2,3 (90 %); 3,0 (95 %); 4,61 (99 %);
n	is the number of units;
t	is the test time.

Alternatively, the lower bound for the MTTF is the reciprocal of the failure rate (λ). If multiple tests m, with n samples and duration t are executed, and zero failures are found, then the term $n \times t$ is to be replaced by the equivalent term, being as shown in Equation (C.4):

$$(nt)_{equivalent} = \sum_{i=1}^{m} (n_i \times t_i) \tag{C.4}$$

If acceleration tests are used, then the acceleration factor for the i^{th} test can be added in the equivalent term.

Example:

Table C.1 shows a test scheme with test hours and number of units for an LED-based product. Three tests are conducted, two with no acceleration and one with an acceleration factor equal to 2. No failures are found in all tests. For each test, the last column gives the equivalent hours and the sum of the equivalent term is equal to 90 000 h. This number can now be used to calculate the upper bound of the failure rate of the LED-based product, by using the Chi-square Equation (C.3).

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[9] Adapted from *Calculating MTTF When You Have Zero Failures*, with the permission of the author(s) (see Bibliography).

Table C.1 – Example test scheme and results for Chi-square.

Test i	**Number of units in test**	**Test hours** h	**Equivalent term** $n \times T \times AF$
1, no acceleration	5	6 000	30 000
2, with AF = 2,0	20	1 000	40 000
3, no acceleration	5	4 000	20 000
Total			90 000

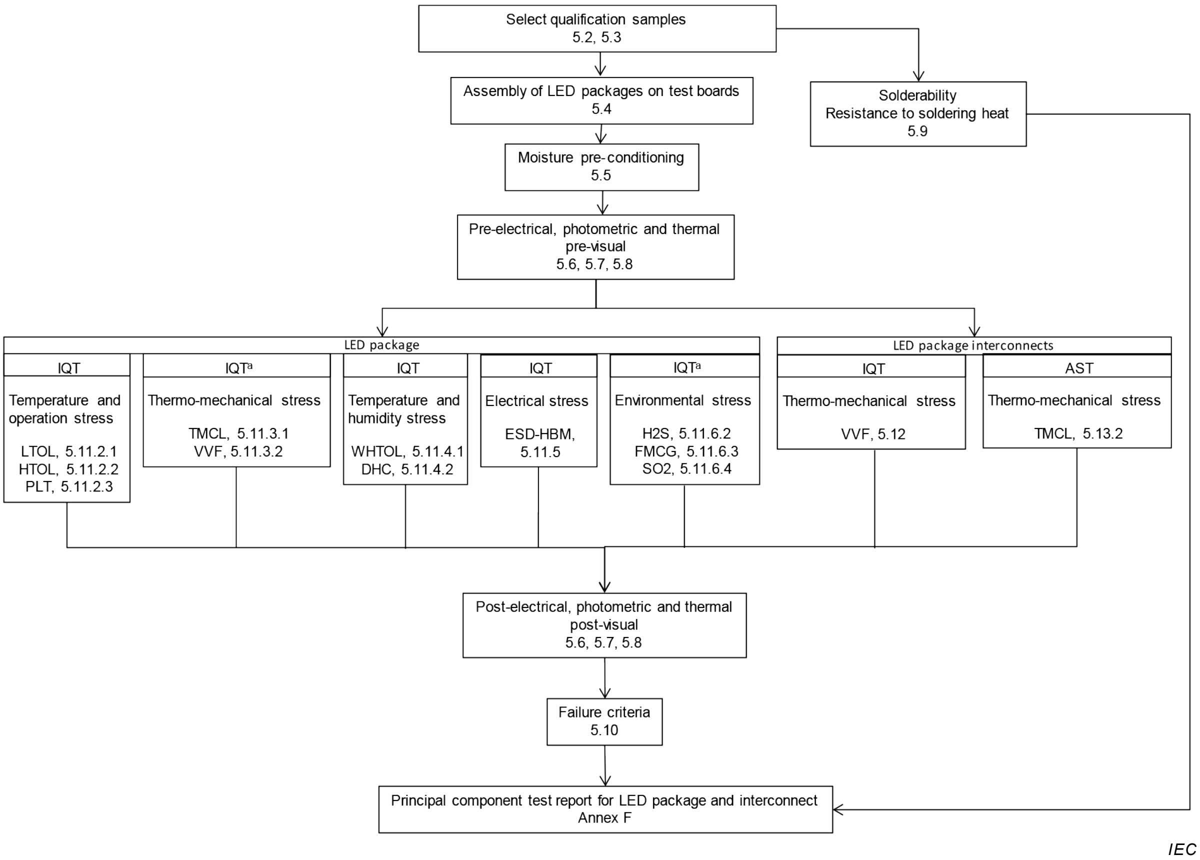
Annex D
(informative)

Qualification flowcharts

D.1 General

The flowcharts presented in Figures D.1 to D.5 refer to Clause 4. These flowcharts can be used as a guideline for the acceleration test schemes of the principal components. The test abbreviations refer to the text in Clause 4.

D.2 Qualification flowcharts of principal components



[a] For the tests VVF, H2S, FMCG and S02, moisture preconditioning is not required.

Figure D.1 – Qualification flowchart for LED package and interconnects

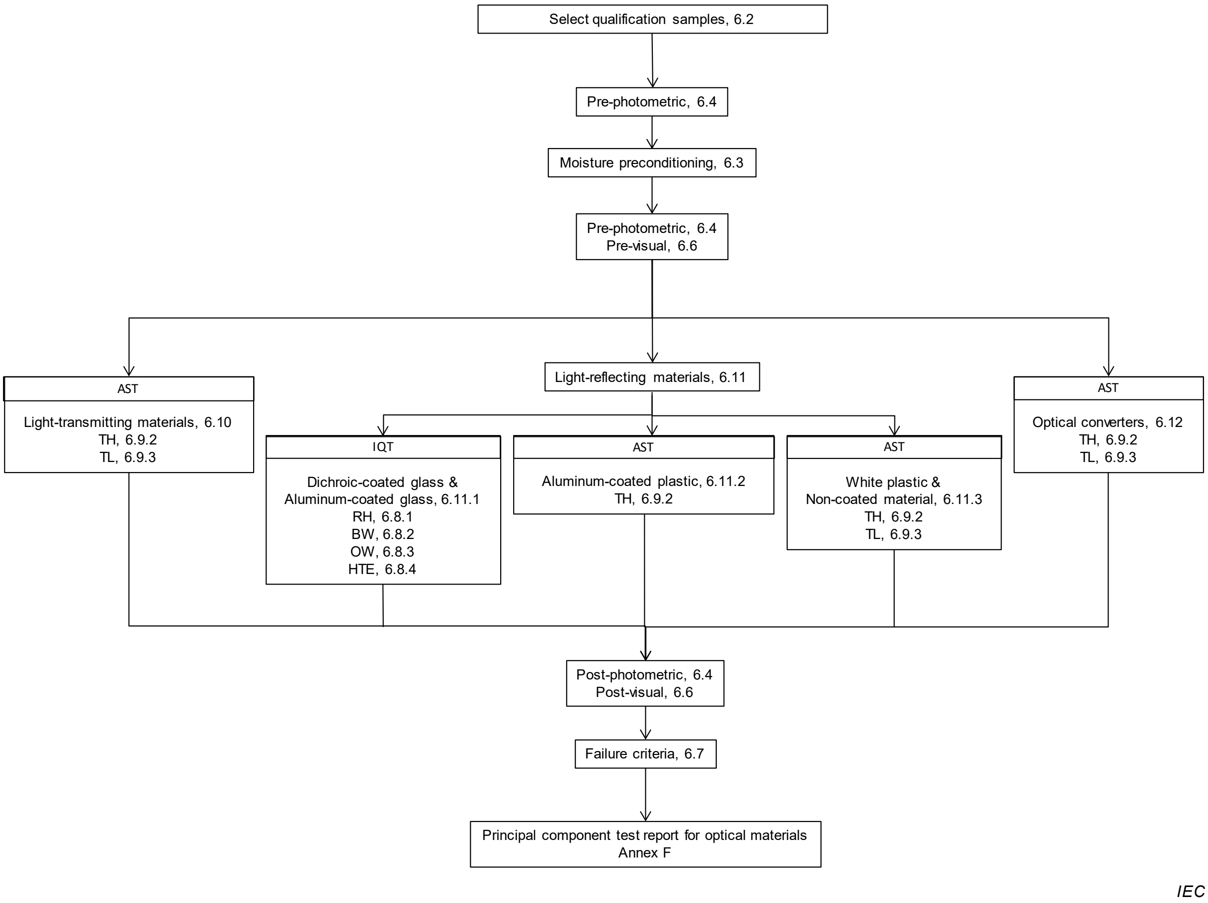


Figure D.2 – Qualification flowchart for optical materials

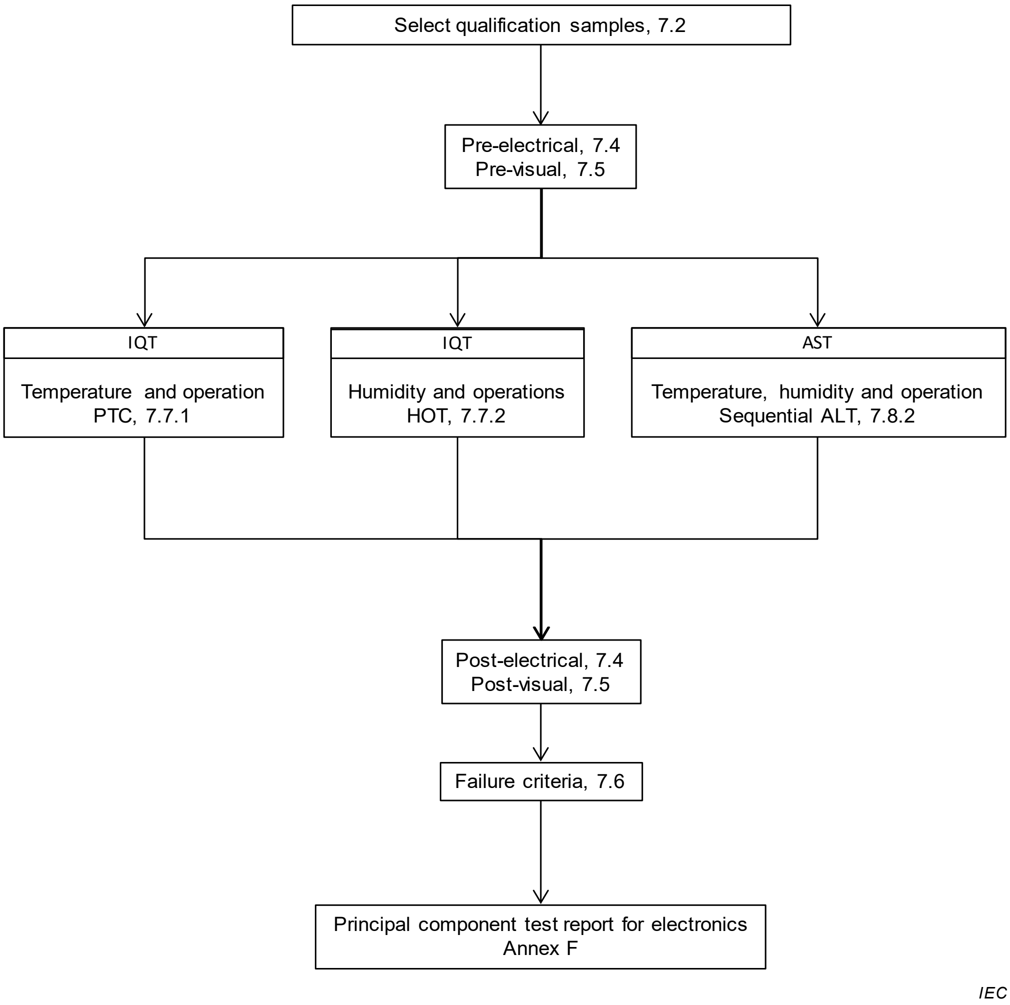


Figure D.3 – Qualification flowchart for electronic subassemblies

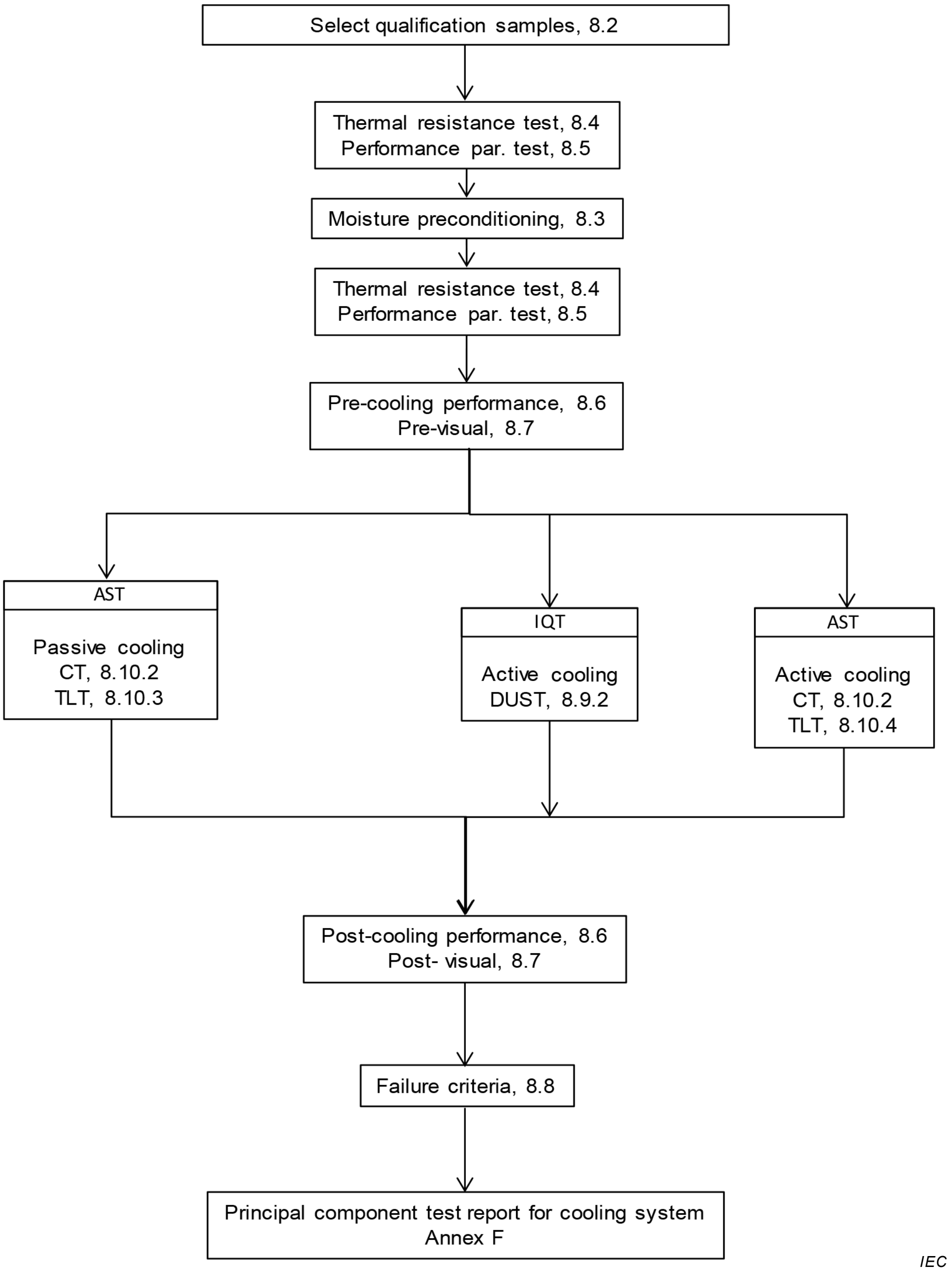


Figure D.4 – Qualification flowchart for active and passive cooling systems

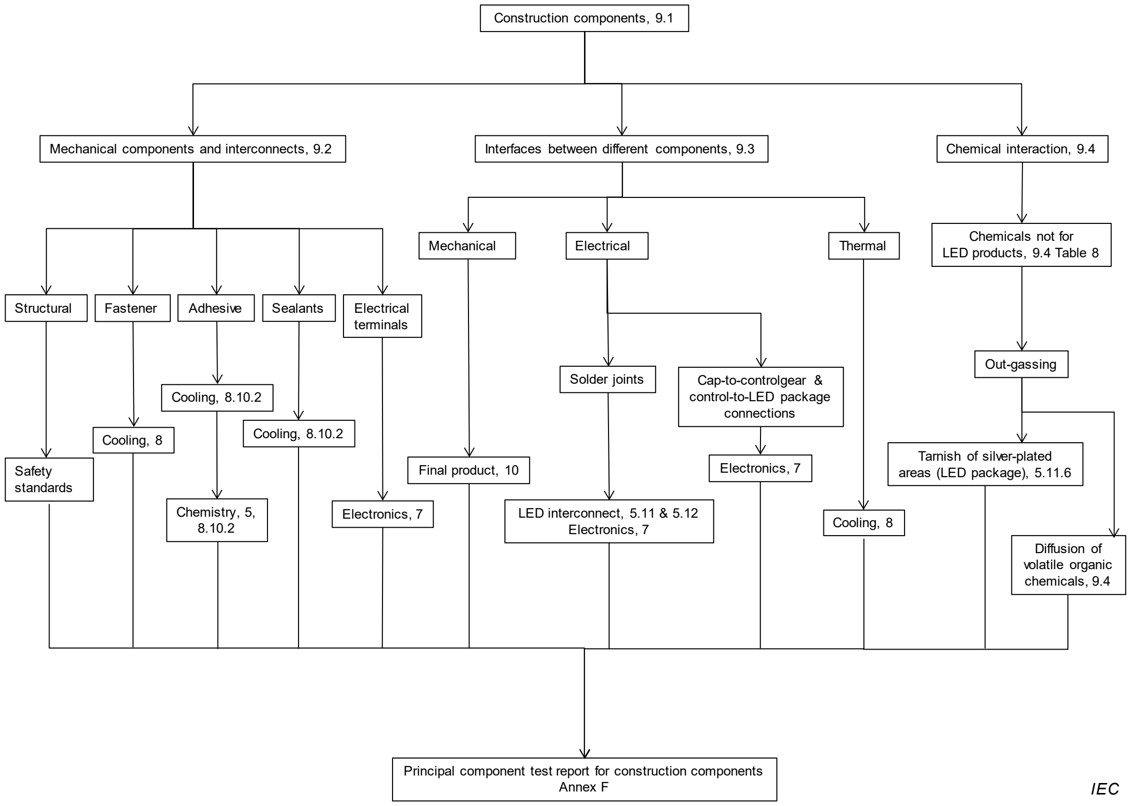


Figure D.5 – Qualification flowchart for construction materials

Annex E
(informative)

Physical analysis for principal components[10]

E.1 General

The purpose of physical analysis both destructive (DPA) and non-destructive (PA), is to determine the capabilities of key interconnects' internal materials, design, and finishing to withstand forces induced by various stresses induced during qualification testing.

E.2 DPA for LED packages and interconnects

The DPA equipment needed for LED packages are:

- optical microscope having magnification capability of up to 50×;
- de-capsulation equipment.

Report the type, calibration range and resolution of the DPA equipment. The DPA procedure for LED packages is as follows.

a) LED packages selected for this test shall have successfully completed temperature and mechanical, and temperature and humidity stress and environmental stress testing as specified in 5.11 (TMCL test, WHTOL test and H2S test).
b) The solder joints shall be prepared by cross sectional cuts in order to expose the cross section of the solder joint and to determine the extent of any mechanical damage/crack. The process used to de-capsulate the LED package shall ensure that it does not cause degradation of the leads and bonds. The internal die or substrate shall be completely exposed and free of packaging material.
c) The LED packages shall be examined under a magnification of up to 50× to the criteria listed below.
d) Failed LED packages shall be analysed to determine the cause of the failure. A failure analysis report documenting this analysis shall be prepared on all failures. If the analysis shows that the failure was caused by the package opening process, the test shall be repeated on a second group of LED packages.

LED packages shall be considered to have failed if they exhibit any of the following:

- visible evidence of non-conformity to the LED packages’ certificate of design, construction and qualification;
- visible evidence of corrosion, contamination, delamination or metallization voids;
- visible evidence of die/substrate cracks or defects;
- visible evidence of wire, die, or termination bond defects;
- visible evidence of dendrite growth or electro-migration.

The DPA equipment needed for LED package interconnects is:

- optical microscope having magnification capability of up to 50×;
- scanning electron microscope (SEM);
- X-ray;

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[10] Adapted from AEC-Q101-REV-C, *Stress test qualification for automotive grade discrete semiconductors*, with the permission of the author(s) (see Bibliography).

- cross-sectional preparation.

Report the type, calibration range and resolution of the DPA equipment. The DPA procedure for LED interconnects is:

a) LED packages selected for this DPA shall have successfully completed mechanical and qualification interconnect stress testing as specified in 5.11 (TMCL test, VVF test, RSH test and H2S test).

b) Interconnects can be examined by X-ray to compare solder joint connection from unstressed LED packages and stressed LED packages according to the criteria listed in 5.10. The X-ray shall be done on mounted LED packages from two directions with maximum possible resolution.

c) Interconnects shall be prepared for cross-sectional examination, by preparing a cross-sectional cut alongside the assembled LED package.

d) The cross-sectional cut shall be examined under a magnification of up to 50× with optical microscope or, if by SEM, according to the criteria listed below.

e) Failed interconnects shall be analysed to determine the cause of the failure. A failure analysis report documenting this analysis shall be prepared on all failures. If the analysis shows that the failure was caused by the preparation process for analysis, the destructive physical analysis shall be repeated on a second group of LED packages.

The LED package interconnects shall be considered to have failed if they exhibit any of the following:

- visible evidence of cracks in the solder joint;
- visible evidence of voids in the solder;
- visible evidence of LED package cracks or defects.

E.3 DPA for optical materials

The DPA equipment needed for optical materials is an optical microscope having magnification capability of up to 50×.

Report the type, calibration range and resolution of the DPA equipment. The DPA procedure for optical materials is:

a) optical materials selected for this DPA shall have successfully completed the qualification testing as specified in 6.8, 6.9, 6.10, 6.11 and 6.12;

b) the optical material samples shall be examined under the magnification of up to 50× to the criteria listed below.

Optical materials shall be considered to have failed if they exhibit any of the following:

- visible evidence of colour change;
- visible evidence of cracks or delamination;
- visible evidence of mechanical damage (deformation).

E.4 PA for electronics

The physical analysis equipment needed for electronics is appropriate power analyser equipment.

Report the type, calibration range and resolution of the physical analysis equipment. The PA procedure for electronics is:

a) electronic subassemblies selected shall have successfully completed the qualification testing as specified in 7.7 and 7.8;
b) power analyser equipment is used to measure any deviations from the initial product specification parameters, in particular:
   - any deviations in power factor;
   - any deviations in the harmonic distortion of the current mains input.
c) failed electronic subassemblies shall be analysed to determine the cause of the failure.

Electronic subassemblies shall be considered to have failed if they exhibit any of the following:

- visible evidence of external cracks;
- visible evidence of mechanical damage (deformations);
- visible evidence of corrosion.

E.5 PA for active and passive cooling systems

The PA equipment needed for cooling systems are:

- optical microscope having magnification capability of up to 50×;
- appropriate thermal analyser equipment, advised are:
  - thermal transient measurement equipment;
  - IR camera of the long wave type (7 μm to 14 μ m wavelength);
  - thermocouples of type Omega AWG 40;
- appropriate power analyser equipment;
- still air chamber;
- heater/cooler plate.

Report the type, calibration range, emissivity settings and resolution of the PA equipment. The PA procedure for cooling systems is as follows.

a) Tested units selected shall have successfully completed the qualification testing as specified in 8.9 and 8.10.
b) Thermal and power analyser equipment is used to measure any deviations from the initial product specification parameters according to 8.8.
c) Failed tested units shall be analysed to determine the cause of the failure.

Tested units shall be considered to have failed if they exhibit any of the following:

- visible evidence of external cracks;
- visible evidence of mechanical damage (deformations);
- visible evidence of interface delamination over 25 % of the surface area;
- visible evidence of corrosion;
- visible leakage of cooling liquids like oil, grease and/or water.

E.6 DPA for mechanical

Subclause 9.3 denotes the categories for the mechanical principal components. DPA and PA shall be followed according to Clause E.1 to Clause E.5.

Annex F
(normative)

Principal component test report

Test and modelling data is only meaningful if all the pertinent test condition information is provided with the actual test and prediction results. Therefore, the example format in Table F.1 shall be used for each principal component in order to supply the following information:

- reference data:
  - type of principal component (e.g. LED package);
  - family it belongs to (e.g. thermal interface material);
  - unique report number, date and possible revision.
- rest data:
  - test item and equipment that is used (e.g. thermal test chamber);
  - test conditions;
  - sample size;
  - test duration.
- rest results:
  - summary of the results;
  - full report, including all analysis (e.g. failure analysis).
- prediction model results:
  - chosen prediction model and the model parameters;
  - prediction results summary and full report.

For each principal component, the above information shall be supplied in a one-page example overview reporting format as given in Table F.1. Details can be documented adjacent to this one-page overview.

Table F.1 – Example overview reporting format

Reference product data			
Principal component:	….	Report number:	….
Family:	….	Date:	….
Test data			
Test item:		….	
Sample & assembly details:		….	
Test equipment:		….	
Test conditions:		….	
Sample size:		….	
Test duration:		….	
Test results			
Test result summary:		….	
Destructive analysis summary:		….	
Failure analysis summary:		….	
Prediction results			
Prediction model:		….	
Model parameters:		….	
Prediction result:		….	
Overall result:		PASS (X)	FAIL (X)

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