

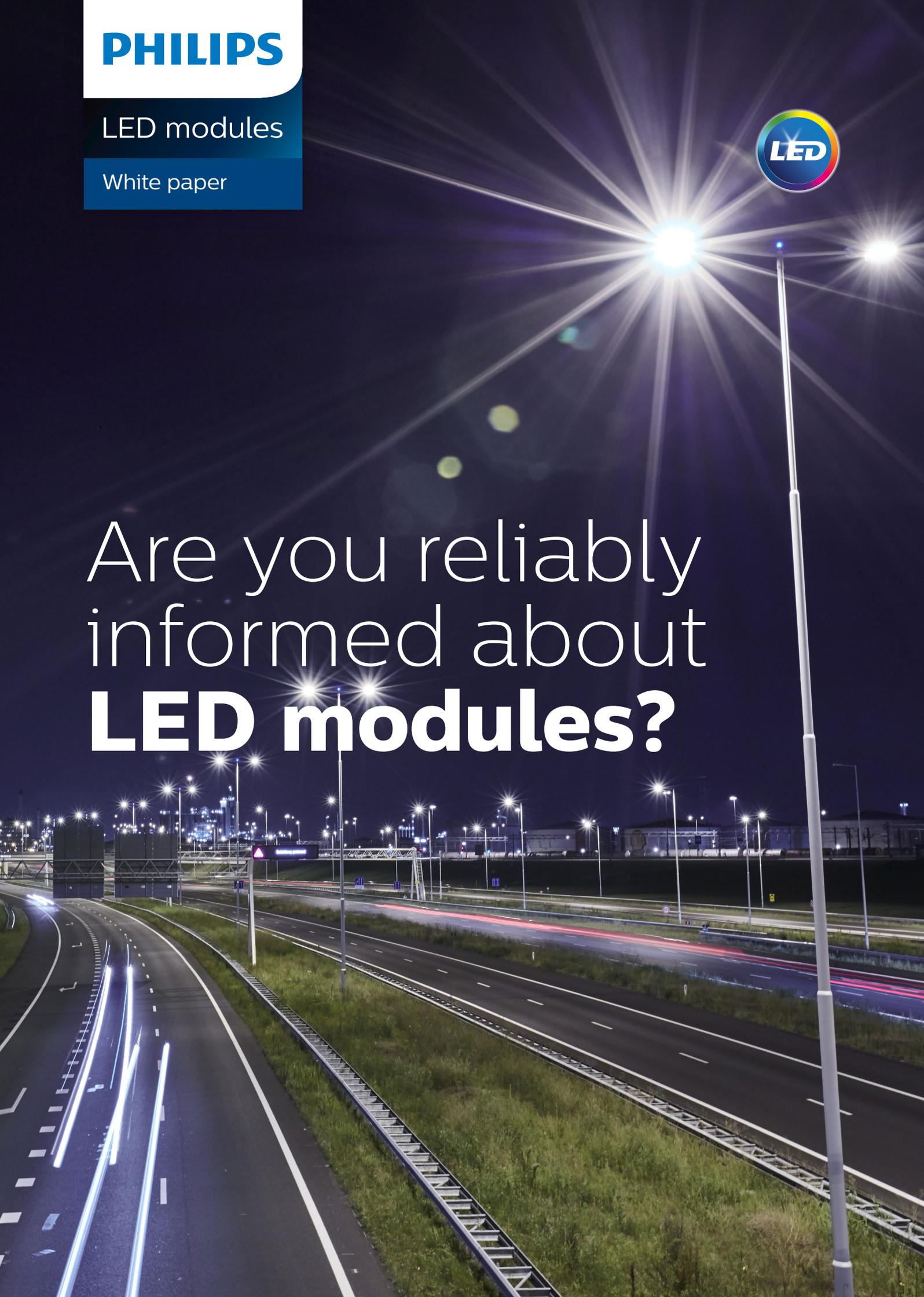
PHILIPS

LED modules

White paper



Are you reliably
informed about
LED modules?



Ensuring LED modules deliver the right light, and the right level of trust

The recent 'LEDification' in the industrial and outdoor lighting segments has rapidly transformed the way OEMs¹ and light source suppliers operate. Indeed, a significant contributor to this transformation is the expected robustness of the LED modules, and their ability to withstand unpredictable conditions to ensure a safe operation in extreme and demanding applications. What's more, the ability to deliver the right light levels at the right time and adjust light levels during critical situations adds to the reasons why the uptake of 'digital' light sources (LED² modules) has proved beneficial to OEMs, offering a variety of form factors, diversity of CCT³, CRIs⁴, a higher level of optical control and, as a result, a higher performance efficacy compared to traditional light sources. It's clear that LED is versatile, robust and low maintenance. But what about LED module reliability?

Reliability is a result of knowledge, consistency and expertise

To give customers, lighting professionals in the field and partner manufacturers the confidence that they have access to the highest quality products and lighting, a reliability program can help to span the full lifecycle of lighting components, from product design and testing to installation and maintenance.

This paper describes the strategy undertaken by *Philips Lighting LED electronics* who assessed their vast experience of reliability testing in conventional lighting and applied the learnings to their **LED module reliability program** which has been developed to maximize the longevity of its LED modules, while gathering accurate, usable reliability data with relevance to lumen maintenance and operating cycles. For example, testing the number of switches a particular module will illuminate under certain temperatures and operating conditions helps us predict the probable lifespan of a module. For the OEM, this means a greater level of trust.

Furthermore, this paper provides actual examples of LED module failure modes that cannot be addressed via the use of LM80⁵ data, or calculations via the TM21⁶ method, therefore demonstrating the risks faced by OEMs when the reliability of an LED module is not considered in a manner as thorough as applied by the **Philips LED module reliability program**.

OEMs and DIY = not the answer

In an attempt to differentiate their new LED propositions, whilst reducing the BOM⁷ of their fixtures, OEMs have experimented in designing and, in some cases, manufacturing their own LED light sources in what is known as taking the DIY⁸ approach.

Unlike the **Philips LED module reliability program**, which evaluates the LED module quality in a holistic manner by testing each one of the sub-components and their subsequent interactions, the aforementioned DIY approach taken by OEMs - often through factors outside of their control - leads to inadequately regulated and standardized design, manufacturing and testing of LED modules, resulting in substandard reliability data and doubt surrounding its quality.

This not only prevents OEMs and their customers from sourcing credible reliability data at LED module level, but also leaves them financially vulnerable should module reliability data be linked to a warranty.

A clear example is the practice of using LED LM80 data, combined with the TM21 tool, to 'define' the reliability values of LED luminaires, resulting in factually incorrect statements such as: '*Luminaire specifications and lifetime of 100Kh are valid for an ambient temperature of 25 C°, according to LM80-TM21*'. This approach only succeeds in misleading OEMs and their customers, as LM80 data is only relevant to the lumen depreciation of a particular LED operating continuously in a clean and stable temperature environment. This is in contrast to the data collected from a catastrophic failure, which is those occurring due to thermal cycling and other influences which represent non-ideal conditions the LED module may be exposed to.

Examine the risks, then eliminate them

For accurate luminaire reliability data, **lumen depreciation**⁹ at LED module level should be considered, whilst factoring in the failure mode (**catastrophic failures**¹⁰) that has the most impact on the lifespan of the LED module, such as switching, temperature swing, drive current, humidity, material outgassing, manufacturing process, PCB and solder quality.

To minimize the risks associated with LED module failure, *Philips Lighting LED electronics* has developed advanced product design and validation methods under the **LED module reliability program** that assess LED reliability and performance on a module level (L2), ensuring products deliver against predicted lifetime specifications.

The program has four key building blocks:

1. quality control
2. testing
3. validation
4. meeting international standards.

Methods such as FMEA¹¹ and advance system modeling (Six Sigma¹²) are used in the design phase, thereafter well-established reliability models and simulations are applied to allow the accurate prediction of product longevity. Moreover, suppliers are carefully selected and repeatedly audited, and inline testing, process control and ongoing reliability tests are fully integrated in product design and specification.

1. Original equipment manufacturer
2. Light-emitting diode
3. Correlated color temperature
4. Color rendering Index
5. Method Measuring Lumen Maintenance of LED LightSources
6. Method of projecting lumen maintenance of LED packages, arrays and modules in actual operating conditions
7. Bill of Materials
8. Do it yourself
9. Luminous flux lost over time
10. Sudden and total failure from which recovery is impossible
11. Failure modes and effects analysis
12. Methodology for eliminating defects driving toward six standard deviations between the mean and the nearest specification limit

The four key building blocks that make a reliable lighting partner



1. Rigorous quality control

Our products, systems and services are built to validated designs and engineered for best-in-class reliability. The Six Sigma standard eliminates product defects, and well-established reliability simulations allow the accurate prediction of product lifetimes. Failure mode and effect analysis (FMEA) is also employed to create a development cycle that constantly improves products.



2. Qualification testing

Before releasing any products or systems to the market they undergo rigorous testing in-house. System architectures are validated at the component, product, and system level using a process of accelerated release and extensive field testing, which enables testing for all potential failure outcomes and the accurate prediction of product reliability.



3. Validation testing processes

Philips employ Advanced Life Testings (ALT), including accelerated thermal tests and stress calculations, to guarantee the lowest product and component failure levels in the industry. There's also functional lifetime tests, tests on multiple performance parameters and their degradation over time in different environments.



4. International standards

For Philips Lighting, complying with international standards is non-negotiable. Among the standards met by Philips Lighting products and systems are IEC 62031 (LED modules for general lighting), IEC 62717 (LED modules for general lighting - performance requirements), IEC 61347 (LED control gear), IEC 60598 (luminaire), PR 15 (electromagnetic compatibility), IEC 62560 (self-ballasted LED lamps), IEC 62861 TS (LED light component reliability testing) and IEC 62368 (product safety).

Quality and reliability in the era of IoT

As lighting moves beyond illumination to become a smart infrastructure capable of powering IoT connectivity, it's essential to ensure compatibility and reliability across multiple connected components and light points. A current example is more frequent switching brought about by smart assets management, which increases the OEM's need for cycling reliability info as fixtures will be switched on and off more frequently (rather than the usual frequency of just once a day). Indeed, according to reliability expert, Willem van Driel, reliability can be a critical advantage to business partners who need to know that the components, products, and systems they are building into their solutions have been designed, built and tested with hyperconnectivity in mind.

Achieving success through finding failure

Before any LED module is released into the market all components are rigorously tested in-house in a process defined as 'building block release'. The building block release which sits at the core of the Philips **LED module reliability program** is a substantial operation where >20 dedicated reliability FTEs¹³ operate as 5 teams from various worldwide locations, testing on average 3,000 LED modules at any given moment. System architectures are validated at component, product, and system levels, using a process of accelerated release and extensive field testing to determine potential failure mechanisms and aid the accurate prediction of product reliability.

The process has repeatedly demonstrated its value and pertinence during years of operation; locating building blocks failures (LED, PCB¹⁴, connectors, etc.) as early as 400 hours into the test, for example. These **failures would otherwise have been overlooked had the supplier's data**

been accepted as 'factual'. Ultimately, the **LED module reliability program** provides peace of mind to OEMs, bridging the reliability knowledge gap that currently exists between LED (L1) and luminaire (L3) level.

Consistency is key

Philips understand that reliability is not just about being able to produce high quality products on a one-off basis, but about consistently being able to do so over time. To that end, control processes are set up to ensure manufacturing quality remains high over time and not only in the first batches or laboratory conditions. In order to guarantee high quality, long lasting products that meet the stated specifications, Philips take a multifaceted approach to quality, including development, supplier and manufacturing quality.

What's more, Philips believe that quality control measures and testing cycles in the manufacturing processes should not become a hindrance to innovation, slow down the innovation process nor have a negative impact on costs. They should be an essential part of a well-considered and realistic quality and reliability process.

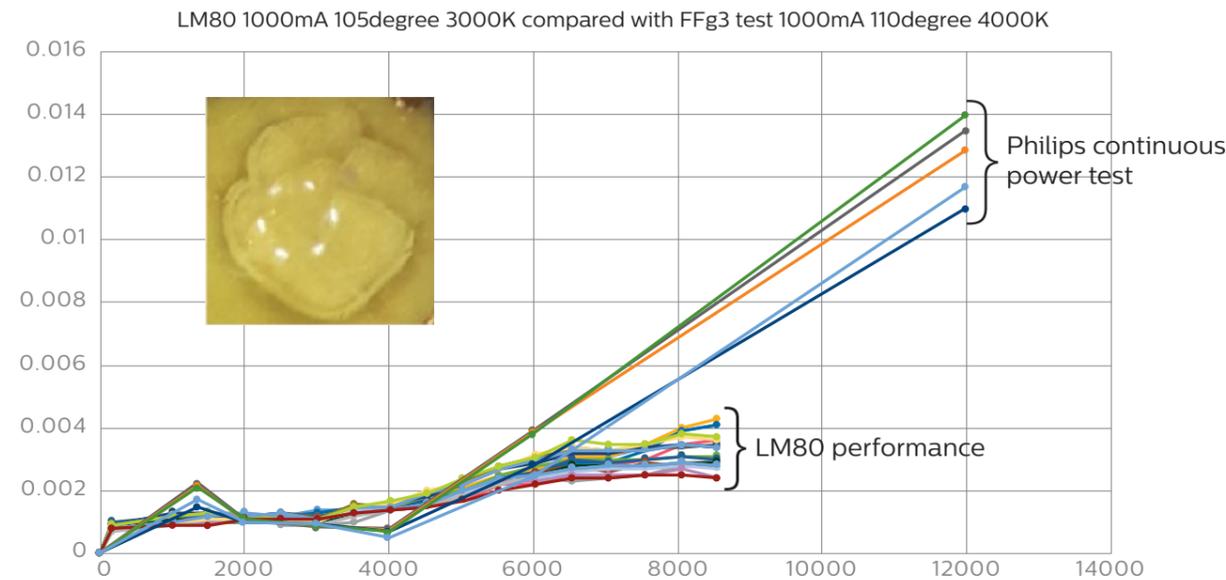
Below are several examples of failures identified by the **LED module reliability program**, which have led to sub-component re-design by suppliers, definition of LED module application limits and, in some cases, rejection of the given sub-component intended for use in a Philips LED module. Also included is a selection of component test results used to pinpoint best-in-class component performance.

¹³ Full-time equivalent
¹⁴ Printed Circuit Board

1. Extreme color shift of high power LEDs due to silicone dome cracking at 12.000 hours continuous power test at high operating conditions.

Result of this finding:

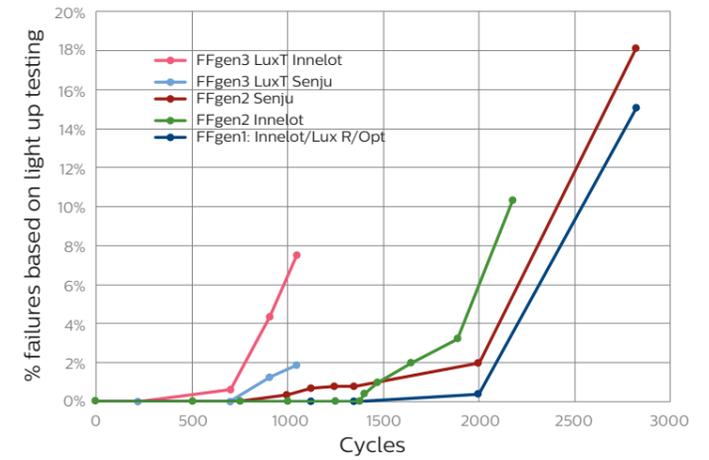
The LED module operating conditions (where the tested LED was implemented) were defined to prevent the LED reaching the given critical operating area, therefore allowing the LED module to deliver the prescribed minimum lifetime.



2. Selection of best performing building block (LED and PCB and solder paste) with respect to solder joint reliability in thermal shock, thermal cycling and power cycling test.

Result of this finding:

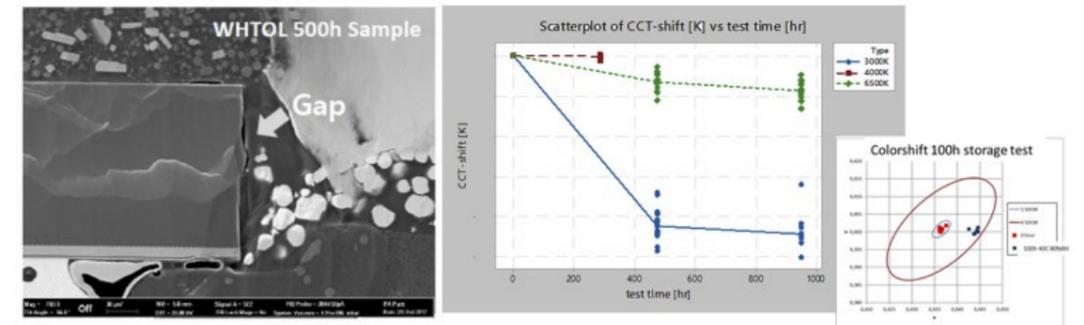
Best performing combination of building blocks were chosen and implemented across the different range of LED modules (customized as well as off-the-shelf); securing the delivery of best possible solder/wire bond reliability performance.



3. Early color shift of medium power LED as a result of low mechanical integrity, detected at 500 hours WHTOL and humid storage test.

Result of this finding:

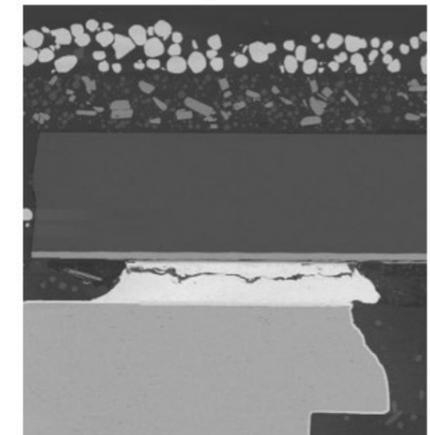
In cooperation with the given LED supplier the findings were analyzed, and corrective measurements were put in place. As a result, a new improved version of the given LED was released and designed-in to several LED modules to bring the performance in line with the Philips Lighting quality requirement that specifies only very limited color shift and lumen decay is acceptable after 1000h in high temperature and humidity conditions (WHTOL).



4. Internal solder joint fatigue in new medium power LED design.

Result of these findings:

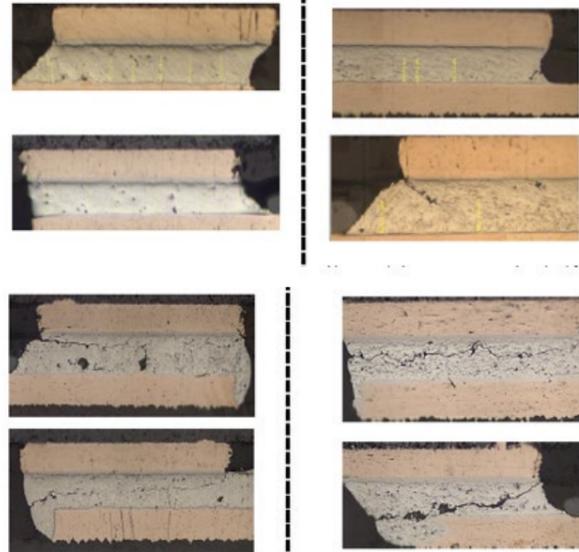
Results from the Philips Lighting tests were shared with the LED supplier, who proposed a series of scenarios to improve the solder performance. In the meantime, the LED module operating conditions were defined to prevent the LED reaching the given critical operating area. This allowed the LED module to deliver the prescribed minimum lifetime.



5. Solder fatigue as a function of the number of LED module operating cycles.

Result of these finding:

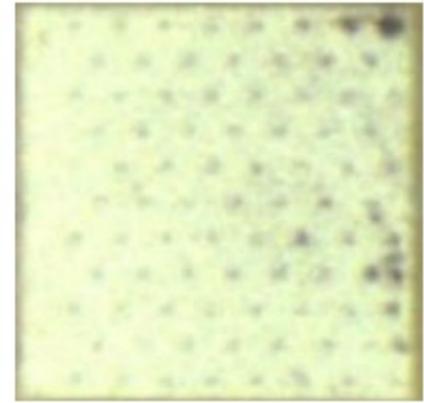
Results of this investigation were used as input during the definitions of the operational windows of several LED modules in the different customized and off-the-shelf portfolios. This allowed the LED modules to deliver the prescribed minimum lifetime.



8. Electrical overstress of high power LEDs at 500hrs power cycling test and high operating conditions resulting from poor die attachment.

Results of this finding:

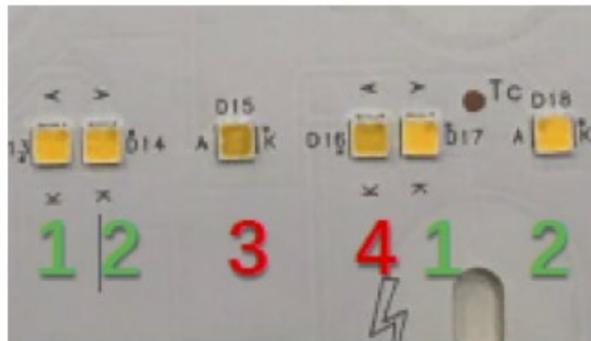
Results were communicated to the supplier leading to an improvement action and the release of a new version which was being tested at the time of this document being written.



6. Batch-to-batch variation of medium power LEDs in corrosion test.

Result of this finding:

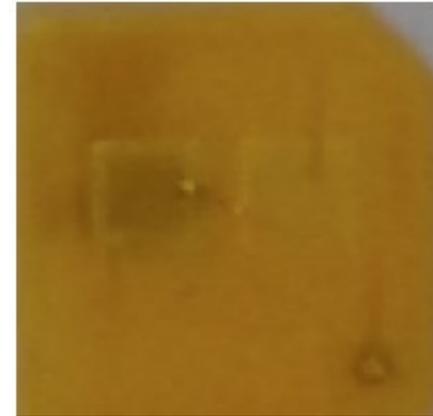
Best-performing LEDs were chosen and implemented across the different LED module families (customized as well as off-the-shelf) according to its robustness and type of application, therefore ensuring delivery of the best possible performance/reliability ratio.



9. Package sensitivity to solder paste material in WHTOL test.

Result of this finding:

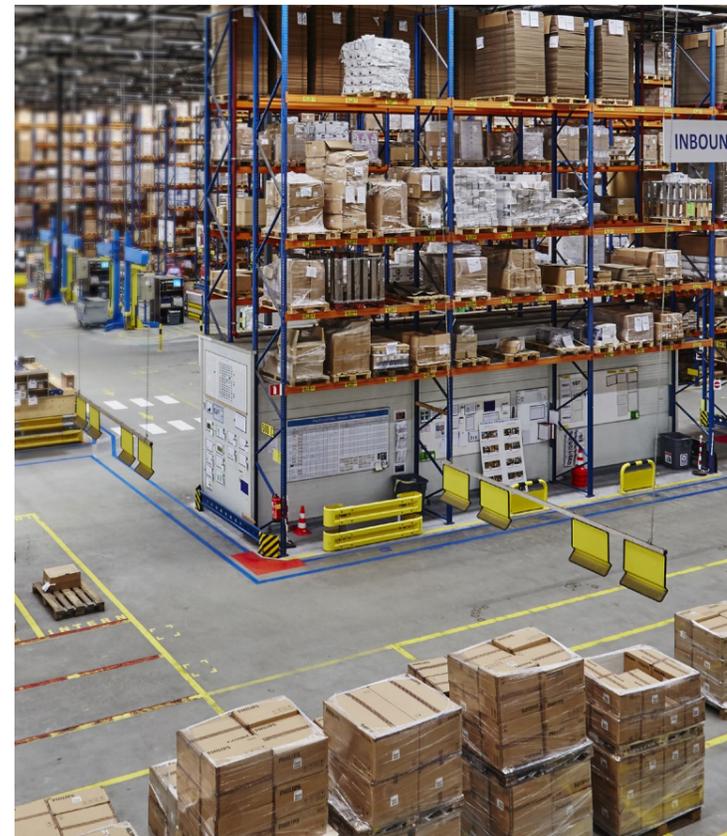
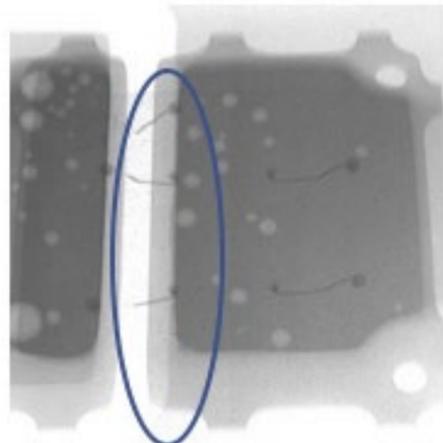
Extensive investigation showed the solder/flux material used was not optimal in combination with this LED package. Therefore a different solder/flux was selected, which proved to be in line with the Philips Lighting reliability requirements.



7. Wire bond break in medium power LED at LTOL test.

Result of this finding:

After the test results were shared with the LED supplier the given LED was discarded as a potential component to be used in a Philips Lighting LED module due to its poor reliability performance.



Conclusions

Based on the data gathered during the release and use in manufacturing of hundreds of building blocks (LED, PCB, connectors, etc.), combined with the multiple failures expertly identified, *Philips Lighting LED electronics* recognizes the growing risk of using sub-components in an LED module without evidence of a full test release and the subsequent production evaluation program.

In addition, it acknowledges the need for consistent and test-based cycling information, which considers the most relevant failure modes and resulting effects on analysis at LED module level, thus avoiding the use of unrelated information such as LED LM80 data, and incorrect assumptions that LED reliability is equal to LED module reliability.

As a solution, Philips offers its **LED module reliability program**, to eliminate the risk of failure, and provide accurate, reliable lifetime data – and a new level of trust – for the OEM and their customers.



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