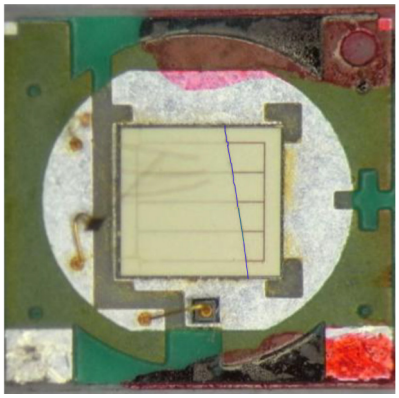
Avoidance of Ceramic-Substrate-Based LED Chip Cracking Induced by PCB Bending or Flexing



LED chip crack (highlighted in blue) due to PCB bending/flexing

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INTRODUCTION

Printed circuit board (PCB) bending and/or flexing is an unavoidable phenomenon that is known to exist and is easily encountered during electronic board assembly processes. PCB bending and/or flexing is the fundamental source of tensile stress induced on the electronic components on the board assembly. For more brittle components, like ceramic-based electronic components, micro-cracks can be induced, which can eventually lead to a fatal failure of the components. For this reason, many standards organizations throughout the world specify the methods under which electronic board assemblies must be tested to ensure their robustness, sometimes as a pre-condition to more rigorous environmental tests such as thermal cycling or thermal shock.

This application note discusses the trends and symptoms observed from failed ceramic-substrate-based LED components in LED luminaires. Cree LED's testing and analysis of such luminaires revealed LEDs that exhibited one or more cracks in the LED chip as well as in the ceramic substrate. It is not the intent of this application note to identify and quantify all the conditions that induce cracks in an LED chip and the underlying

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ceramic substrate, but to explain some prevalent causes of PCB bending and flexing resulting in cracks and to suggest some actions to minimize their occurrence.

The Multi-Layer Ceramic Chip (MLCC) capacitor industry has heavily investigated component cracks caused by PCB bending/flexing. When a populated circuit board is bent, a significant amount of tension is directed to the ceramic capacitor through the solder joints as the board forms an arc. Ceramic material is inherently hard and brittle, with no elasticity, so any stress induced by bending the PCB is directly transmitted to the body of the ceramic-based electronic components. Since this stress must be released somehow, cracks can result on the ceramic-based electronic components. Immediate detection of cracks and/or failures in the affected components may not be possible because the characteristics and/or symptoms may not manifest as a fatal or catastrophic failure. With continued operation of the component and exposure to humidity in the environment, further degradation of the crack(s) occurs, eventually leading to a fatal/catastrophic failure of the affected component.

Such phenomena have also been observed in LED board assemblies that are populated with ceramic-substrate-based LED components. LED luminaire manufacturers have encountered a failure mode that is typically reported as “no light output”, “dimmed light output” or “flickering light output.” When such samples were analyzed, a crack in the LED chip in-line with a ceramic-substrate crack was typically observed.

LED LUMINAIRE ASSEMBLY

In a typical LED luminaire, the LED board is secured to the aluminum heat sink/housing using one or more metal screws. Thermal grease or a thermal pad is typically applied between the LED board and the aluminum heat sink to help with thermal conduction during luminaire operation. An electronic driver circuit may be included either internal or external to the luminaire depending on the size and design constraints of the luminaire. Figure 1 shows an example of a typical LED luminaire. Figure 2 shows LED boards secured to the underlying heat sink assembly with screws.

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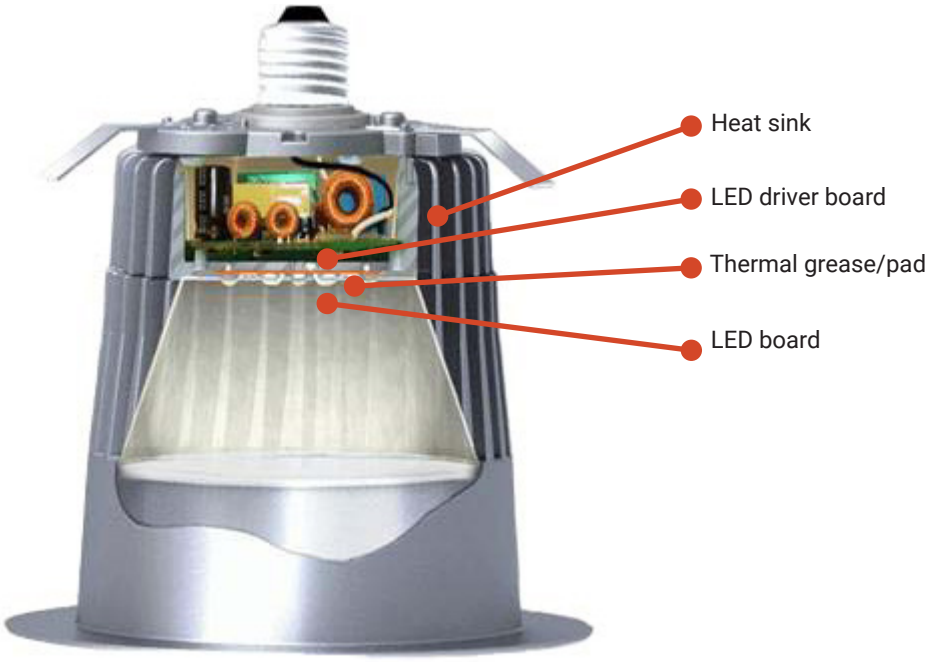

Figure 1: Example LED luminaire

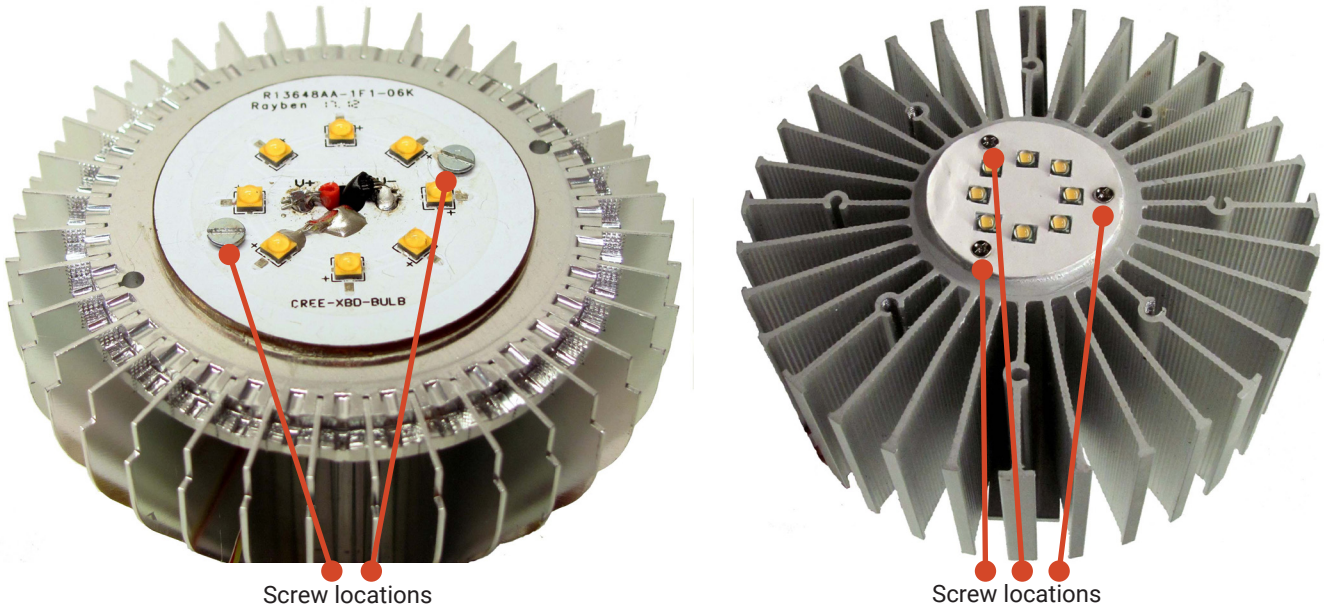

Figure 2: Examples of LED boards attached to a heat sink. Metal screws are typically used in addition to thermal grease/tape to ensure close adhesion to the underlying heat sink assembly.

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WHAT CAN CAUSE PCB BENDING/FLEXING?

Following are situations in which a PCB can bend or flex, resulting in cracks in an LED chip attached to it.

1. Screw tightening/torquing

Manual tightening or automated torquing of metal screws is typically used to attach an LED board to the heat sink assembly during LED luminaire manufacturing. PCB flexing, which occurs due to the board's natural characteristic to form an arc when it is deflected, can easily occur during this process, inducing stress directly on the ceramic-substrate-based LEDs soldered on the PCB. This force is transmitted through the solder to the ceramic substrate and to the eutectically attached LED chip. Figure 3 is a pictorial representation of the directions of stress applied to an LED during PCB bending/flexing.

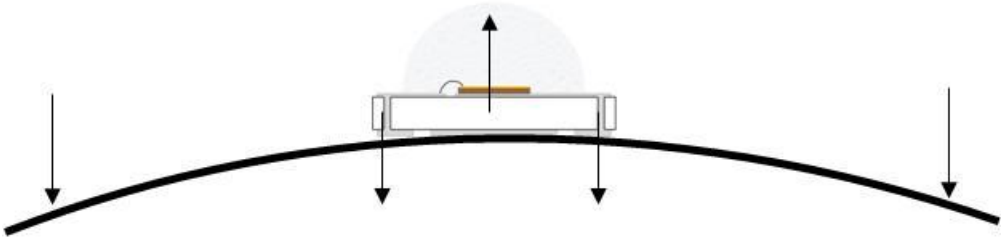

Figure 3: Direction of stress forces applied to LED when PCB is bent/flexed

2. Uneven/convex PCB surface

PCB flexing can be amplified if the surface to which the LED board is being attached is uneven, warped or convex. This can easily occur during manual application of thermal grease if the amount dispensed is not controlled or if it is applied unevenly. Applying a layer of thermal tape or thermal grease only under the LED may be sufficient to conduct heat away from the LED chip during its operation, however this creates an undesirable convex or uneven surface to which the LED board is attached, which in turn causes PCB bending/flexing during the screw tightening process, exerting stress on the LED. Even if it covers the entire surface of the board, a thick thermal tape layer under the LED board is also not necessarily the best solution when it comes to preventing board flexing. Same as the partial/uneven surface effect, overtightening the screws can occur due to the resilience of the thermal tape material. This, in turn, causes PCB bending/flexing to occur.

3. Reflow soldering the LED board

PCB warping or bending can occur during the LED board assembly reflow soldering process, especially if materials of greatly different coefficient of thermal expansion (CTE) make up the PCB. Stress can be applied to the LED during this process by the volume of solder used to attach it to the underlying PCB surface. Using an excessive amount of solder can lead to greater susceptibility to thermal stress, resulting in cracks at the solder joint as the LED gets hot.

4. PCB punching/separation

For manufacturing efficiency, LED board assembly manufacturers typically populate multiple LED boards at once with the boards tied together. After the reflow and/or test process, a punching tool or a manual breaking process is then used to separate the LED boards. During this separation process, PCB bending/flexing can easily occur, exerting excessive stress on the ceramic-substrate-based LEDs that are soldered onto it, causing a crack.

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Operator mishandling of the LED board assembly during this process is another area that should not be overlooked when investigating a root cause of LED component failure related to board bending/flexing.

TRENDS OBSERVED FROM LED CHIP CRACKS INDUCED BY PCB BENDING/FLEXING

Cree LED's analysis of failed LED luminaires revealed the following trends.

1. LED chip crack is in the same direction as the substrate crack

One of the primary failure modes observed in LED chips used in LED luminaires is an LED chip that exhibits leaky and/or shorted LED current/voltage characteristics. Most of the time, a crack in the ceramic substrate onto which the LED chip was soldered can be observed in addition to the LED chip crack. Both cracks are in the same direction and in line, meaning if the crack in the ceramic substrate was extended, it would look as though the crack continues to the LED chip. This is a good indication that the cracks in the LED chips were induced by cracks in the underlying ceramic substrate. Figure 4 shows an example LED exhibiting this trend.

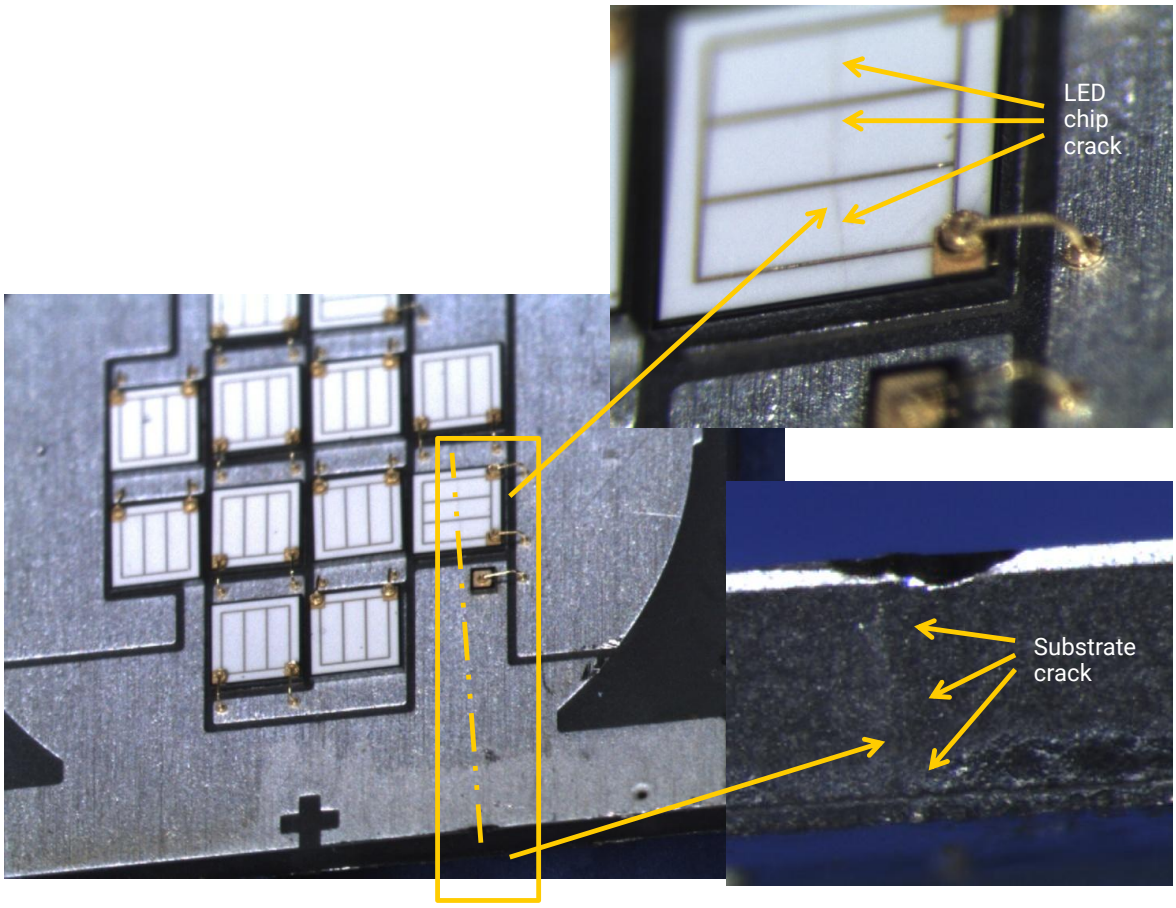

Figure 4: Crack observed on ceramic-based multichip LED in same direction as ceramic substrate crack

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2. Cracks in the LED chip and/or ceramic substrate perpendicular to PCB bending/flexing direction

Another trend observed from the LED chip cracks was that, for assemblies that used an even number of screws, the direction of the cracks was always perpendicular to the axis of the screw locations. Figure 5 shows a damaged LED chip that was removed from an LED luminaire. The LED board was attached with two screws.

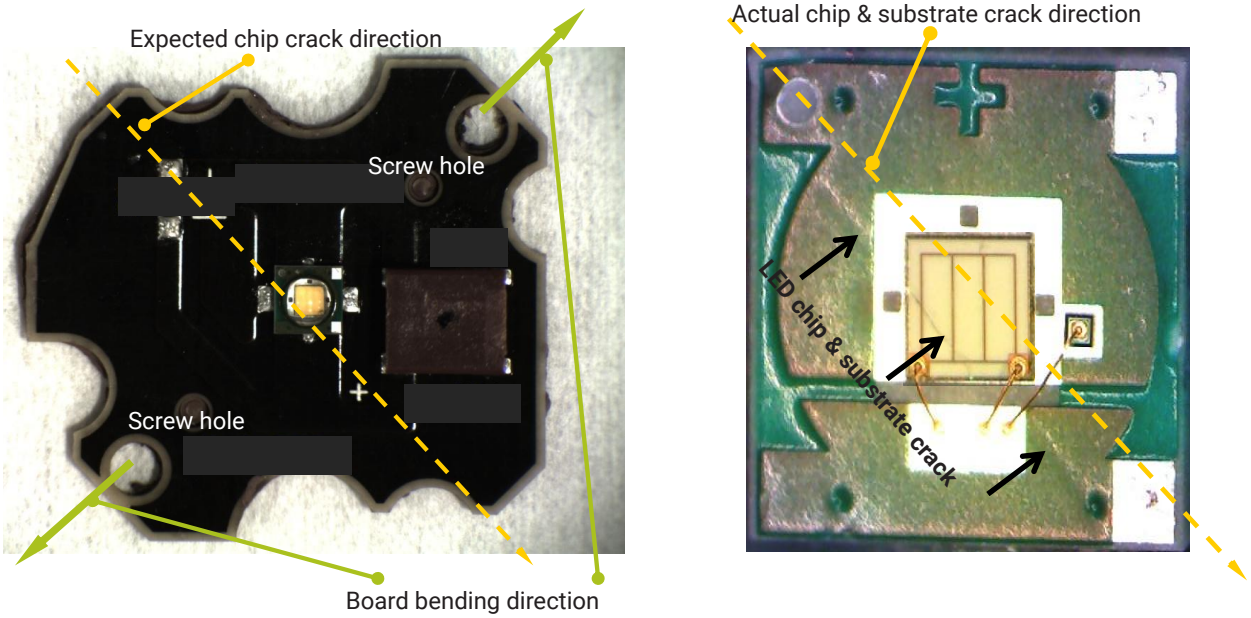

Figure 5: LED crack perpendicular to the stress direction. Image on the right is a close-up view of the PCB on the left.

3. Cracks in the LED chip in the shape of an arc

If an odd number of screws was used to attach the PCB, the cracks observed on the LED chip were in the shape of an arc in the direction opposite the board bending direction. Figure 6 shows a damaged LED chip that was on a PCB attached with three screws.

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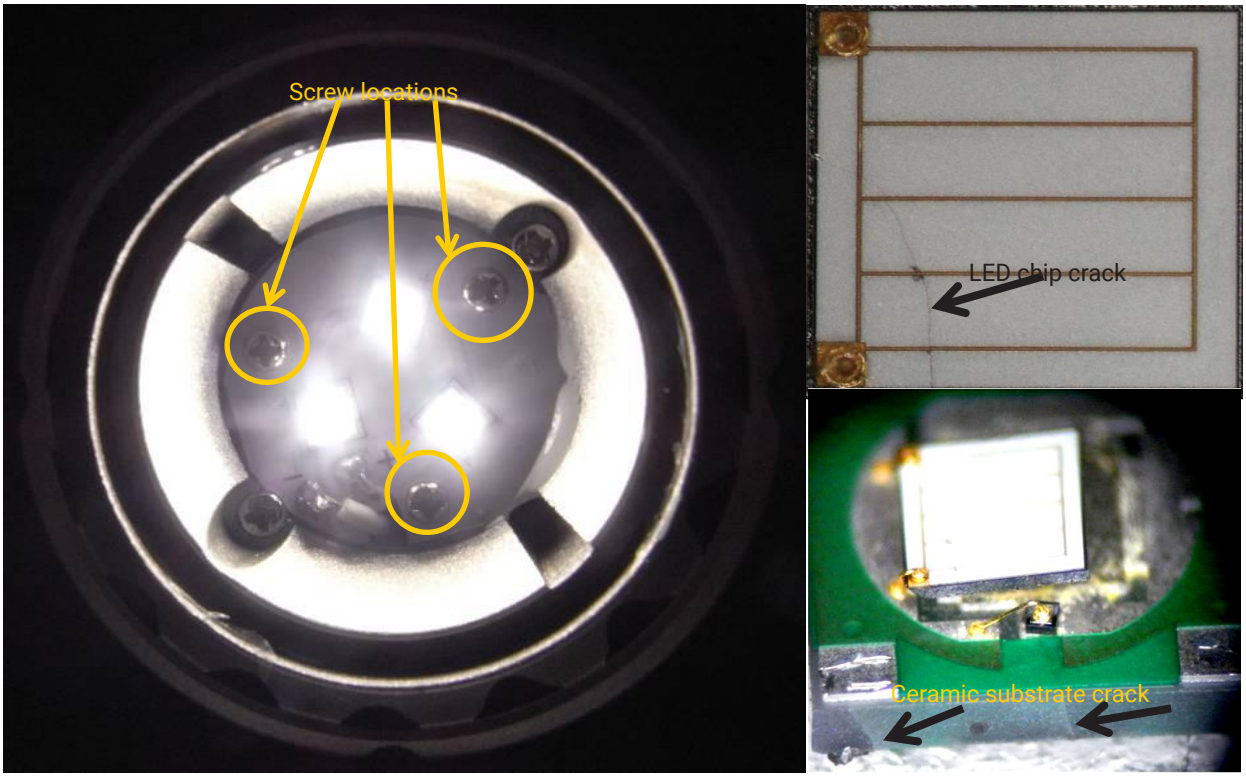

Figure 6: LED chip crack in an arc shape. Images on the right are close-up views of the LED lamp on the left.

SUMMARY

Cree LED has identified cracks in the LED chip and substrate as the root cause of the unstable, partial or no emission failures observed from ceramic-substrate-based LEDs that were used in LED luminaires. This failure mode was more predominantly observed in MR16- or GU10-type fixtures. All LED luminaire manufacturers who experienced this failure mode used one or more metal screws in addition to thermal grease or tape to fasten a PCB populated with one or more ceramic-substrate-based LEDs to a heat sink housing. The metal screws were fastened or tightened either manually using a hand-held screwdriver or by an automated process using a known torque force.

Cree LED's analysis results observed from failed LEDs indicated PCB bending/flexing is the most likely root cause of LED component failure and some trends observed are worth noting. They are:

1. Cracked LED chip damage is seen only on ceramic-substrate-based LEDs. Metal-frame-based LEDs do not exhibit PCB flexing induced cracks.
2. Cracks in the LED chip are always in line with cracks in the ceramic substrate, if present.
3. If an even number of screws is used to fasten the LED board to the heat sink assembly, the direction of the crack on the LED chip and/or ceramic substrate is always perpendicular to the PCB bending/flexing direction.
4. If an odd number of screws is used to fasten the LED board to the heat sink assembly, the crack on the LED chip is in the shape of an arc.

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5. The larger the LED component, whether in single- or multi-chip form, the more susceptible it is to crack damage.

PCB bending/flexing is an unavoidable phenomenon that exists in the electronic board assembly industry, including LED boards. This PCB bending/flexing that can cause cracks in the LED chip which in turn cause a catastrophic failure in the LED component can be minimized if the following cautions are practiced.

1. Do not overtighten the screws when attaching an LED board to a heat sink.
2. Always use automated torquing and tightening of the screws with set torque force.
3. Do not use an excessive amount of thermal grease or a thick thermal tape/pad.
4. Do not manually apply thermal grease; use a controlled-volume dispensing method.
5. Do not use partial application of thermal grease or tape, i.e., application under the LED component only. An even spread and controlled volume are critical to minimize possible board bending/flexing during the fastening process.
6. Do not mount an LED board on a warped, convex, or uneven surface.
7. Do not use an excessive amount of solder to attach an LED to a PCB.
8. When designing an LED board, consider using materials close in CTE to minimize CTE mismatch during thermal exposure.
9. When handling LED boards after assembly, always ensure that the boards are properly supported to minimize board bending/flexing.
10. If LED boards must be separated after assembly, ensure that the boards to be separated are firmly supported in a fixture that prevents them from being flexed or bent.
11. When designing an LED board, ensure that the size and weight of the LEDs are evenly distributed on the board to prevent possible bending/flexing during thermal exposure.

Further investigation of PCB bending/flexing induced failures to determine specific, quantified steps to minimize this occurrence in their luminaires is left to luminaire manufacturers.

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