Smart Molded Structures Bring Surfaces to Life

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Abstract
This paper introduces structural electronics technology enabling smart molded structures. It also presents a case for developing industry standards specific to structural electronics materials, processing and testing.

In the first part, we outline the benefits of structural electronics technology as well as the manufacturing processes. Smart molded structures are made by integrating and encapsulating printed electronics and standard electronic components within durable, 3D injection-molded plastics. Structural electronics technology and processing differs significantly from conventional electronics. Thus, we describe how these differences influence component and materials certification for use within injection molded plastics.

In the second part of the paper, we discuss the lack of suitable standards for structural electronics. Two technologies, bearing a resemblance to structural electronics, have standards. However, they do not cover all aspects and we see a need for further development.

Part 1: Structural Electronics

Introduction to Structural Electronics Technology and Manufacturing

Structural Electronics technology enables design innovation by integrating electronic functions into 3-dimensional injection molded plastic structures. Features, such as controls, sensors, illumination and communications, are embedded in thin 3D structures with plastic, wood and other surfaces (Figure 1).

Figure1 - Structural electronics can also have natural surface finishes.

The structures are light, thin and durable. In conventional use cases, such as an in-vehicle control panel, a single part replaces a multi-part conventional electronics structure and eliminates labor-intensive electro-mechanical assembly. The part also weighs less and is significantly thinner. The company has demonstrated structural electronic designs with 70% weight and 90% thickness reduction when compared with conventional multi-part assemblies (Figure 2).

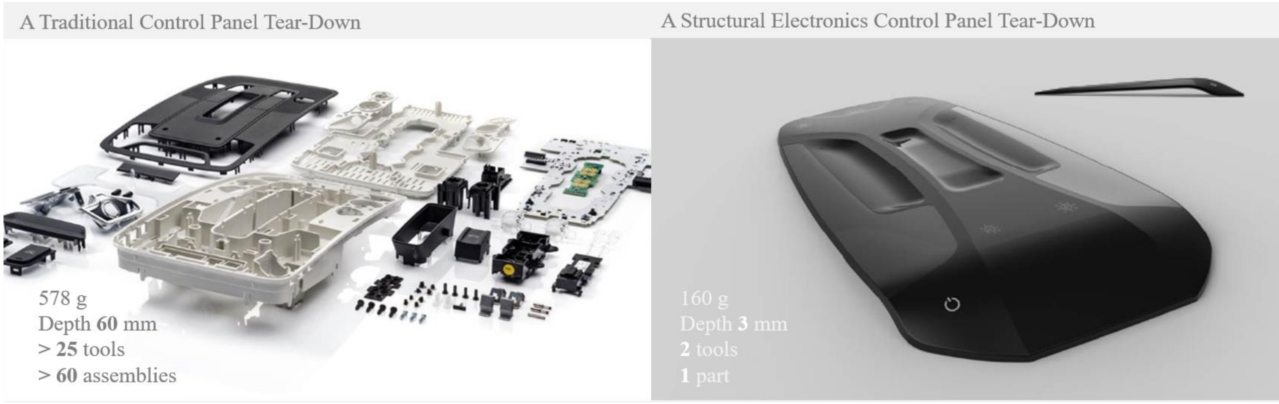

Figure 2- The company has demonstrated structural electronics designs with 70 % weight and 90 % thickness reduction when compared with conventional multi-part assemblies.

Core manufacturing processes for structural electronics are printing, surface mounting, forming and injection molding (Figure 3). Taken individually, these processes are mature and we use standard equipment suitable for mass production. However, the standard processes are combined in a unique way during manufacturing of structural electronics.

Printing is the first core manufacturing process. Electronics and decoration (graphic inks) are printed onto plastic film or another suitable substrate material. Electronics are typically printed using silver (Ag) conductive inks and dielectric inks to insulate between layers of circuitry. The outputs are two kinds of films: electronic and surface. The latter films are used for decorations, such as icons for human-machine interface. In some cases, a single film can be used for both decoration and electronics. Both films can also be substrate for electronics.

Surface mounting technology (SMT) is the second core process. Components are placed and bonded, mechanically and electrically, onto electronic films. The output is 2D (two-dimensional) film substrate with components.

Forming is the third core process. Two-dimensional electric and graphic films are thermoformed into three-dimensional shape and trimmed as needed. Outputs are 3D electric films with components and 3D graphic films.

Injection molding is the fourth core manufacturing process. Three-dimensional electric films and 3D graphic films are used as inserts in an injection molding tool, and plastic resin, such as polycarbonate (PC) is injected between the films resulting in a single molded part. The output is a strong and durable structure in which electronics are encapsulated within the molded plastic. Figure 4 illustrates the material stack. Structural electronics manufacturing often includes also pre-assembly and final assembly of control electronics.

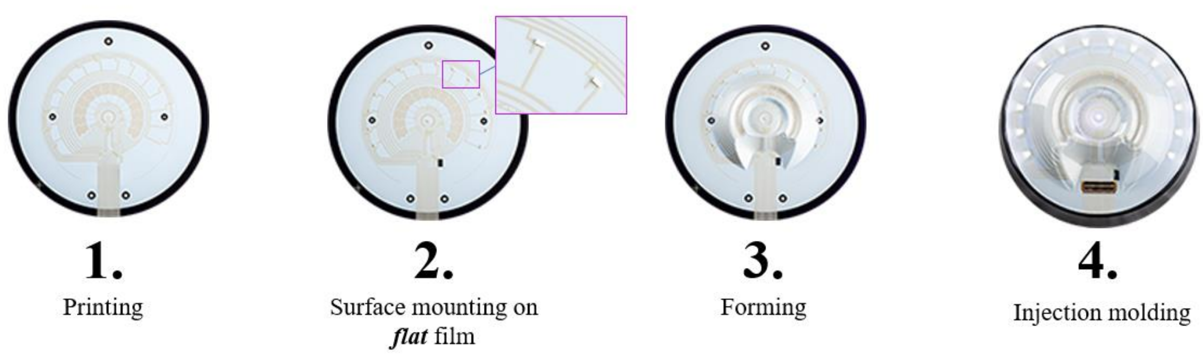

Figure 3 - Core manufacturing processes for structural electronics

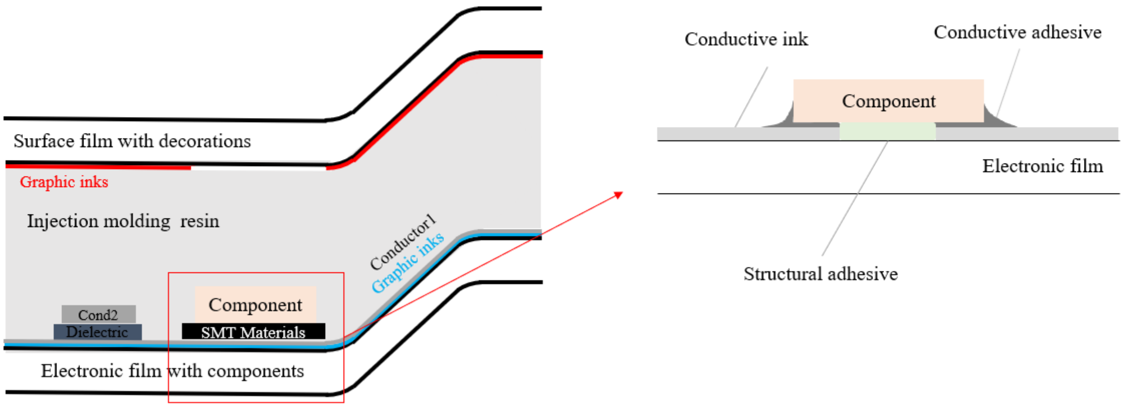

Figure 4 - Typical material stack in structural electronics

Introduction to Component Certification Process

Structural electronics technology differs significantly from conventional electronics. Currently most electronic components are optimized for conventional electronics manufacturing that does not anticipate the temperature and pressure exposure of thermoforming and injection molding processes. Thus, the company certifies all electronic components that are embedded inside injection molded polymers. Certification has three steps (Figure 5).

The company has defined the requirements for ideal component packaging [1]. During pre-screening component data is compared with the ideal package. The component package does not need to fulfill all requirements to pass this step. However, there are some items that cause failure at pre-screening. For example, a package with moisture sensitivity level (MSL) of 4 or higher fails.

If a component passes the pre-screening, the company manufactures test platforms with that component using internal company standards for certification layout and material stack. Components undergo surface mounting, forming and injection molding and they are tested after each process step. The testing system is also standardized.

If the manufacturing yield is sufficient, the test platforms are subjected to reliability testing. Typical environmental loads are change of temperature as well as elevated temperature-humidity. Based on test results and physical failure analysis, components can receive certification for use in commercial projects.

[1] T. Simula et al, "Component Packages for IMSE (Injection Molded Structural Electronics)," in Proceedings of NordPac, Oulu, Finland, 2018.

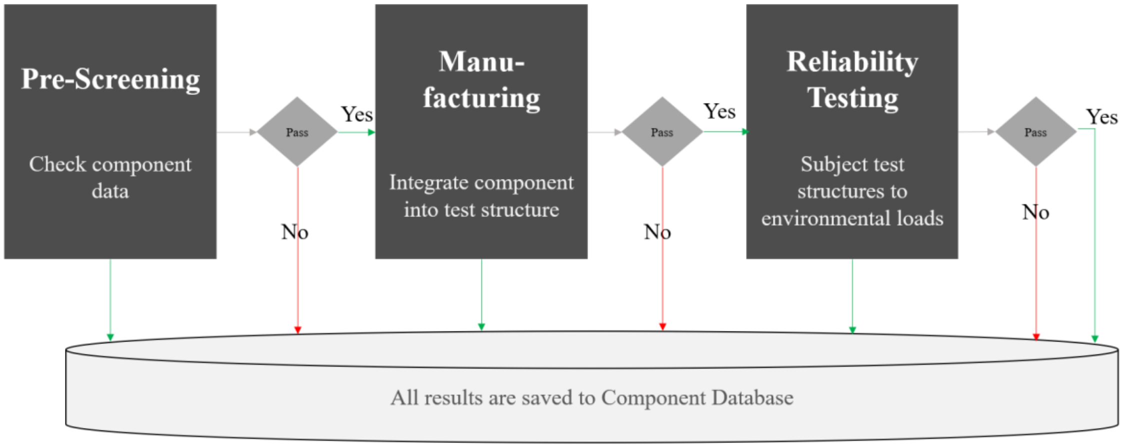

Figure 5 - Component certification process flow.

Reliability Testing Results

The results presented here are part of the Certification Process for Type1-LED that was tested using an internal certification platform, Figure 6. Each certification platform contains 48 Type1-LEDs. We have surface mounted some of the Type1-LEDs on top of small radius 3D-curves. This is against our design guidelines but we wanted to push the limits of the technology and gain understanding on potential failure modes under adverse conditions. Figure 7 shows a summary of the tests and sample sizes.

Figure 6 - Photo of two certification platforms that were subjected to extended reliability testing.

At the end of the reliability tests, we checked the functionality of the Type1-LEDs. The Rapid Change of Temperature test did not cause any Type1-LED failures, all of the 480 Type1-LEDs were functional after 1000 cycles between -40 ◦C and +85 ◦C. Steady-state temperature-humidity (85◦C/85%RH) caused one Type1-LED to fail. The failed LED was in a certification platform that had been powered on during testing. The other 479 Type1-LEDs were functional after 1000 hours of elevated temperature and humidity. We also measured light luminance and color coordinates from some of the tested Type1-LEDs. Reliability testing did not cause any adverse effects.

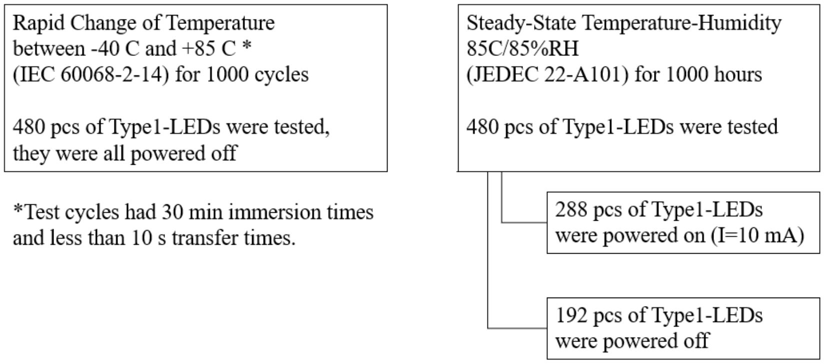

Figure 7 - Summary of tests and sample sizes in Type1-LED reliability testing

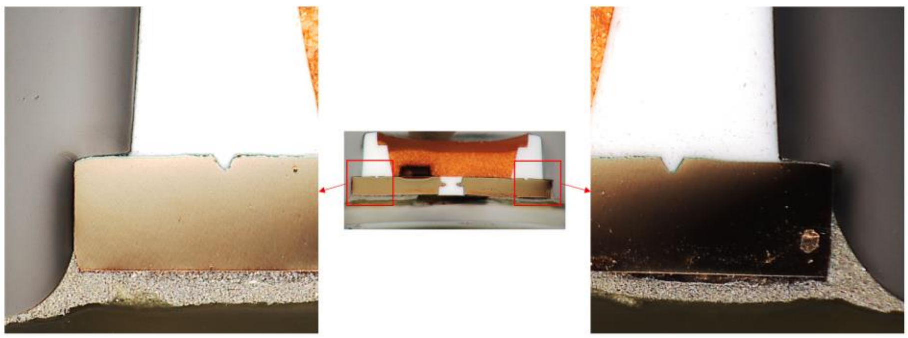

Figure 8 – Cross-section shows slight bending of component base and partial delamination of conductive adhesive.

Physical Failure Analysis Results from Type-1- LED

Electrical measurements indicated that the failed Type1-LED had a component internal short-circuiting. Nevertheless, we made a cross-section of the failed component because it had been mounted on top of the thermoformed 3D-curve. The cross-section showed that the component base had bent slightly. In addition, the conductive adhesive bond on one side had partly delaminated, Figure 8. As stated before, component mounting to 3D-curves with small radius is against our design guidelines.

Extended Reliability Testing Results

Testing until failure is useful for better understanding structural electronics reliability. That is why we tested one of the company demonstrator products for 3000 cycles in the change of temperature test. The demonstrator product, shown in Figure 9, contains 20 pieces of Type2-LEDs. Figure 10 shows summary of the tests and sample sizes.

Figure 9 - Photo of a demonstrator product that was subjected to extended reliability testing.

Change of Temperature
between -40 C and +85 C *
(IEC 60068-2-14) for 3000 cycles

20 pcs of Type2-LEDs were tested,
they were all powered on (I=15 mA).

*Test cycles had 1 h exposure (i.e. dwell) times and 1 hour ramp times. One test cycle lasted for 4 hours.

Figure 10 - Summary of the test and sample sizes in extended reliability testing

Two Type2-LEDs failed during 3000 cycles. Failures occurred at 702 and at 2988 cycles. When we fit this data into a Weibull distribution, we predict 50 percent failure point at over 10000 cycles, Figure 11. Such a high value demonstrates the reliability of the technology. However, the number of tested components was small in the extended reliability testing. Thus, we have subjected more certification platforms to extended reliability testing.

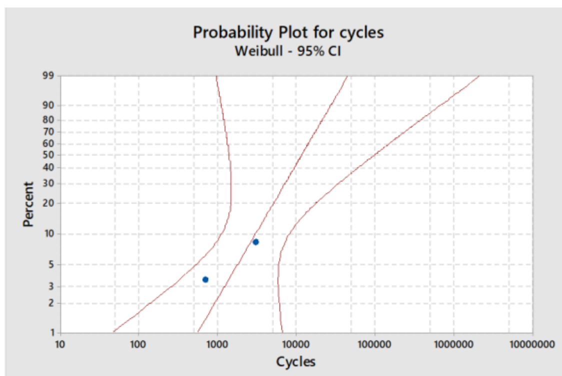

Figure 11 - Extended reliability testing failures in Weibull-distribution

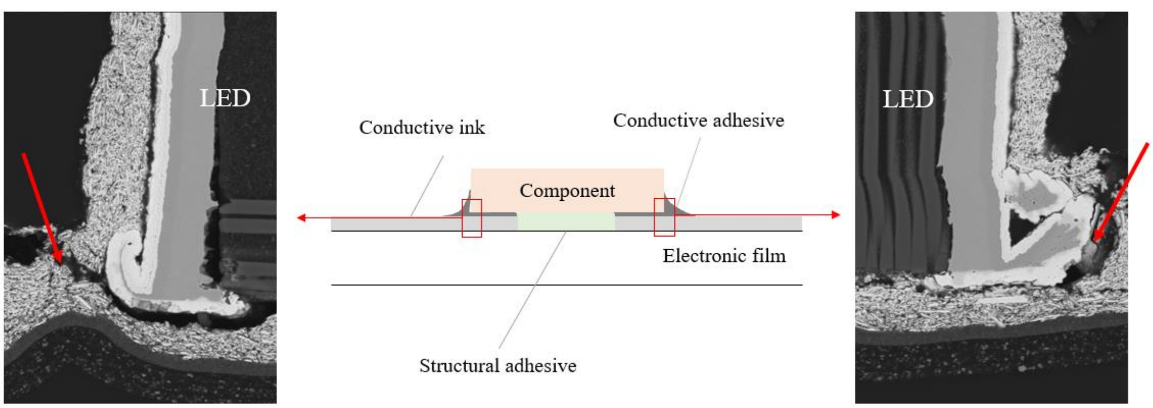

Figure 12 - SEM-images of the cross-section show fracture in the conductive adhesive used for surface mounting.

Physical Failure Analysis Results from Failed Type2-LED

We performed cross-section and scanning-electron-microscope (SEM) analysis on a failed Type2-LED. It showed that the failure mode is a fracture in the conductive adhesive used for surface mounting the component to the electronic film, Figure 12. The failure mechanism is conductive adhesive creep caused by thermo-mechanical stresses during thermal cycling.

Conclusions

We have demonstrated structural electronics designs with 70 % weight and 90 % thickness reduction when compared with conventional multi-part assemblies. Structural electronics is also a reliable technology. The tested certification platforms and demonstrator products endured thermo-mechanical stresses and elevated temperature-humidity. Injection molding resin strengthens the structures and also protects electronics from environmental conditions, such as moisture, dust and mechanical impacts.

Part 2: Standardization for advanced technologies

Many PCBA Standards Are Not Applicable for Structural Electronics

Structural electronics technology differs significantly from conventional electronics. This means that many PCBA standards are not relevant for structural electronics. For example, the IPC-9704 - Printed Circuit Assembly Strain Gage Test Guideline defines strain limits to the rigid PCB during assembly process. The company substrates are thin and flexible plastic films. They inherently bend and cannot comply with the strain limits made for rigid PCBs. Even if IPC-9704 is a guideline, some manufacturers require compliance to it from their suppliers.

Printed circuit boards also tolerate higher temperature than most plastic films. Typical maximum operating temperature for FR-4 is around 130 ◦C. Many elevated temperature and thermal cycling tests assume that the substrate material is FR-4. Thus, they have maximum temperature of 125 ◦C or even 155 ◦C. Typically, structural electronics substrate materials cannot tolerate those temperatures. Furthermore, temperatures such as 125 ◦C or 155 ◦C may not be relevant for the application environment.

Two Similar Technologies Have Standards

Printed electronics and device embedded substrate technologies bear a resemblance to structural electronics. Figure 13 shows their definitions. The company follows Printed Electronics Standardization developments in IEC and in IPC. We have also acquired relevant IEC standards for Device Embedded Substrates.

Printed Electronics	Device Embedded Substrates
Devices and systems using printed electronics processes during their manufacture.	Substrate in which active device(s) (semiconductor device) and/or passive devices(s) (e.g. resistor or capacitor) is formed using thick film technology or embedding them within the substrate.

Figure 13 - Definitions for Printed Electronics and for Device Embedded Substrates

We welcome the fact that Device Embedded Substrates standards recognize thermal limitations of substrate materials. For example, standard IEC 62878-1 ED1 states, “Compared to the test severities applied to bare printed wiring boards, limitations exist, which are determined by the sensitivity of embedded components and substrate material. Requirements and severities shall be defined between user and supplier.” In our opinion this is a good practice because user and supplier can select temperatures that are relevant for the application environment.

Two Organizations Create Printed Electronics Standards

IEC and IPC are both active in Printed Electronics standardization. They have organized the Printed Electronic standard development work into (Technical) Committees. Figure 14 shows the Working Groups and Sub-Committees in them. The standardization scopes are similar even if the naming differs. By August-2018, both organizations had published around 10 standards for printed Electronics [2, 3] and both organizations have many standards in the pipeline.

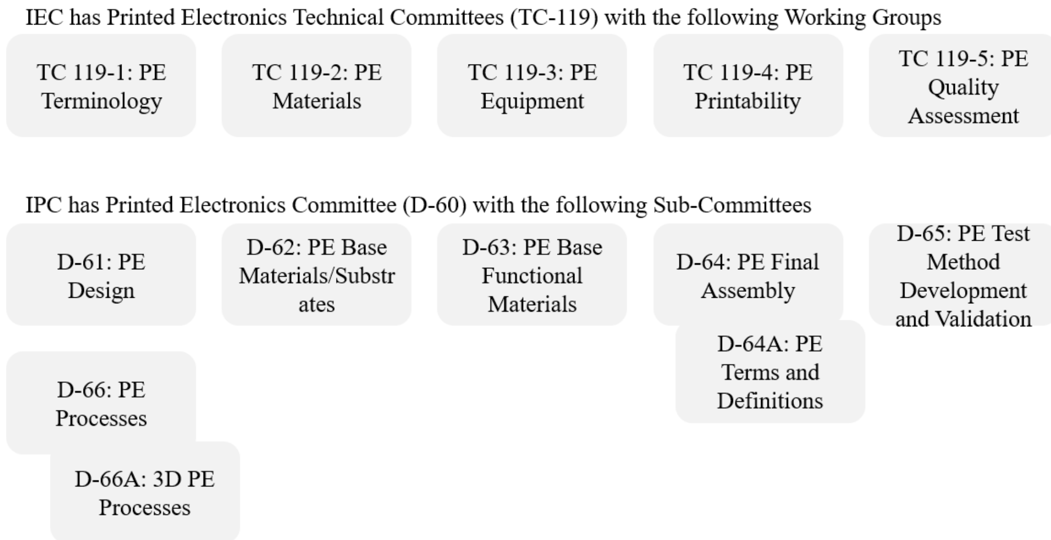

Figure 14 - IEC Working Groups and IPC Sub-Committees in Printed Electronics [4, 5]

Structural Electronics Technology Needs New Standards

Current Printed Electronics standards lack information that is important for structural electronics. An example is a method for resistance-strain measurements. During thermoforming, two-dimensional films with conducting layers are formed into three-dimensional shapes. The films and conducting layers deform plastically. Printed Electronics standards have some deformation related items [6, 7, 8, 9]. However, the deformations and stresses are in elastic region only.

For companies to design reliable structural electronics solutions, they must know how conductive layer resistance changes as a function of plastic strain. This information is seldom available from ink suppliers. Moreover, there is no shared measurement or analysis methodology. Thus, results cannot be compared between ink suppliers. The company made resistance-strain measurements for conductive inks in 2015. The company has continued developing the method since and is

[2] IEC Web-Store, https://webstore.iec.ch. Accessed on 2018, Aug-10, search keyword was "IEC 62899".

[3] IPC Online Store, http://shop.ipc.org/. Accesses on 2018, Aug-10, search keyword was "printed electronics".

[4] IEC Standard Development Working Groups. http://www.iec.ch/dyn/www/f?p=103:29:9535300622184::::FSP_ORG_ID,FSP_LANG_ID:8679,25#1. Accessed on 2018, Aug-10.

[5] IPC Public Groups. https://ipc.kavi.com/higherlogic/ws/public. Accessed on 2018, Aug-10.

[6] Standard IPC-4921, Requirements for Printed Electronics Base Materials (Substrates).

[7] Standard IPC-4591, Requirements for Printed Electronics Functional Conductive Materials.

[8] Standard IEC 62899-201-2, Printed electronics - Part 201-2: Materials – Evaluation methods of stretchable substrates.

[9] Standard IEC 62899-201-4, Printed electronics - Part 201-4: Materials – Evaluation methods of stretchable functional ink (conductive ink and insulator layer).

looking to refine it into an international standard. If a test method standard becomes an IEC or IPC standard, will the other standard organization develop a similar one but with different test methods and requirements? The company will not want this to happen. In a truly global industry, such as (structural) electronics, it would be a waste of effort to have overlapping work in two standardization organizations with co-operation and similar standards being the goal.

Conclusions

Structural electronics uses flexible plastic films as substrates. Thus, the standards that are based on typical PCB stiffness and temperature endurance are not applicable for structural electronics. In the company's opinion IEC Device Embedded Substrate standards have selected a good approach that does not hinder the utilization of new and evolving technologies which could be adopted in other standard documents. Those standards allow the user and supplier to select temperatures that are relevant for the application environment. We welcome this approach and hope to see it in other standards going forward.

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