ARLON ELECTRONIC MATERIALS

APPLICATION NOTES

Continuous Operating Temperature

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The Up's and Down's of Continuous Operating Temperature

- What determines "Continuous Operating Temperature" of a system and how does that differ from Tg?
- What are the Continuous Operating Temperatures of common laminate systems?
- Can I relate "Continuous Operating Temperature" to service life of my board under real-time conditions?

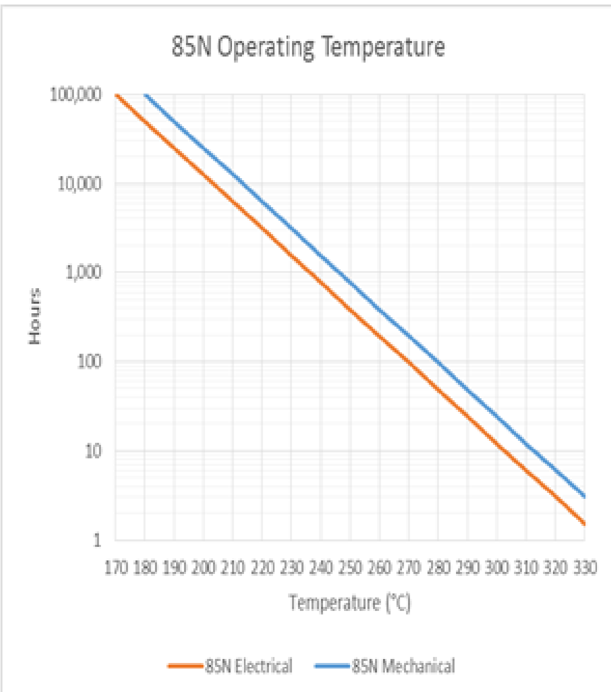
The truth is that no answer to this question will ever totally satisfy a board designer with specific conditions in mind, and only some kind of accelerated testing of an actual board or assembly will give a meaningful answer.

Continuous operating temperature is the temperature at which a particular material can operate without undue deterioration for a long period of time. The first trap is the word "continuous" because it implies "forever" and that will never be the case. So someone has to stop and ask "At what temperature..?" and "For how long..?" For instance, if you wanted to use the product to check core temperatures in a volcano, our standard measures of "continuous operating temperature" would quickly prove inadequate.

There are many ways to evaluate this. We measure Tg (glass transition temperature - typically not an indicator of long term performance) and look at thermal decomposition via TGA (thermogravimetric analysis - which looks at the temperature at which a material starts to come apart rapidly, also not necessarily an indicator of long term stability at some lower temperature). Short term testing at various temperatures (T260, T288 and T300) give an indication of short term thermal stability suitable for determining process and soldering stability, but not related to long term performance. Underwriters Laboratories(UL) developed a Relative Thermal Index (RTI) that may be the best general indicator of extended life at specific temperatures; given that it looks at specific properties and not at the broad spectrum of functional performance crtiteria. All of these are indicators of relative performance and allow comparisons between materials. For many reasons, no single approach will necessarily be able to provide one easy-to-use number that can reliably be taken as the "Continuous Operating Temperature." We will look at why this is the case.

The UL RTI uses an Arrhenius plotting of time vs temperature based on a four point thermal aging study, similar to the idealized graph shown in the illustration below, for materials which is the mathematical extrapolation of data from a four temperature accelerated aging evaluation to a temperature at which the material will operate for 100,000 hours and still retain at least 50% of its original physical or electrical properties. Typical properties tested are tensile strength (physical) and dielectric breakdown resistance (electrical).

Remember, however, that the maker of a PWB wants their entire board to operate for a long period of time, and most data available on materials was specifically developed on the unclad laminate composite, (resin and glass). The internal structure of the board itself, (amount of heat sinking capacity and density of power-generating components), as well as the intended use environment, will also affect the service life of a board.



It is quite possible that a PWB that has less than 50% of its original tensile strength and less than 50% of its original dielectric breakdown voltage will still work perfectly well in its intended application. At best, these are indicators rather than absolutes, and good judgement should continue to play an important role in assessing how they relate to your application.

I am often concerned when the UL RTI is used as an absolute, rather than a relative performance indicator. While the UL RTI may not identify the ultimate use temperature of a material, it is a good starting point guideline. Although, use above that temperature will result in increasingly rapid failure. The UL plot is logarithmic and in a relative sense you can quickly estimate what will happen as you increase (or decrease) temperatures.

Oxidation is the principal mechanism by which epoxies and polyimides embrittle and turn brown as they sit or operate at high temperatures over a period of time. Above the Tg this process occurs more rapidly because of greater diffusion rates and more molecular motion. As with many chemical reactions, the rate at which it proceeds roughly doubles for every 10° C temperature increase. With polyimide, for example, although it turns brown fairly quickly, this is mostly a surface oxidation and not a deep deterioration of the material. Lower temperature materials, epoxies with fairly labile bromine and the like will deteriorate substantially at temperatures which are relatively innocuous to polyimide.

Oxidation is also the major cause of long term failure of copper bonds on PWB's. Copper traces oxidize not only on the top side,(where they turn purple or black), but also underneath due to diffusion of oxygen. When the treatment that bonds the copper to the surface oxidizes sufficiently, the bond will fail and the line will fall off with relatively little handling.

Not one of the standard thermal indexing values relates to this phenomenon, which will occur as a function of the rate of diffusion of oxygen under the copper traces and as a function of temperature. The use of a protective coating that will inhibit surface oxidation and absorb UV will help to substantially prolong the life of any material.

Polyimide is clearly the most thermally stable of the available resins in the marketplace with an RTI (for a rigid board) of 170/180 (electrical/mechanical). Materials such as BT with RTI of 140/150 or FR5 epoxy with RTI of 130/140, (note that FR-5 is not inherently more thermally stable than FR-4 – it is designed to maintain its rigidity at a higher temperature than FR-4 but this does not indicate thermal stability per se), will not have the survivability at high temperature of polyimide.

Prolonged temperatures over 250°F will eventually deteriorate copper bonds on any PWB surface. This is a primary mechanism for failure of copper bonds on Teflon® boards which otherwise are entirely resistant to normal oxidative, (or almost any chemical), attack on the resin itself. Use of designs with "Pads Only" surfaces, or employment of high temperature conformal coatings will significantly extend the service life of a board under such conditions.

TROUBLESHOOTING TIP: It is always important that a designer test the materials he is choosing to ensure that they will actually perform acceptably in their intended use. This is not a cop-out to avoid responsibility for the performance of our materials. Neither we, nor any laminator, can ensure that our material will perform in conditions that are out of our control. There needs to be a good early dialogue between the designer and the laminator to discuss needs and specifications and make sure they select the best available material for the job. This will minimize the risk of designing boards that will fail prematurely.

BLATANT COMMERCIAL MESSAGE: The best available laminate resin for long term high temperature applications is Arlon's 85N and 85HP, which is a pure polyimide with no flame retardants or other thermally unstable additives. Where optimal thermal performance is needed, we don't know of any material with superior property retention at high temperature. It is used, for example, in downhole drilling applications where a combination of high temperature, corrosive environment and high humidity tend to eat inferior materials in a very short time.

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