Modeling Temperature Driven Wearout Rates for Electronic Components

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Electronic components generally experience functional wearout where 1 or more physical processes lead to degradation of the component as is it used in a circuit. Wearout is typically experienced at a macroscopic level where the component no long conducts current.

Wearout processes are almost always accelerated by temperature. This means that for an electronic component with a room temperature service life (e.g. a measured average of 100,000 hours for a representative sample of units) the actual service life will be a lesser amount at higher temperature.

The Arrhenius Equation is typically used to model the acceleration of the temperature dependent physical processes that lead to functional wearout:

C_R = M * e **($-E_a$ / k T) [M times e raised to exponent ($-E_a$/kT)]

C_R	is the "Process Rate Coefficient" (applies to chemical as well as physical processes)
M	is an experimentally determined constant specific to the materials and methods used
e	= 2.718281
E_a	is the "Activation Energy" for the physical process(es) that lead to wearout, in eV
k	is Boltzmann's Constant, 8.617×10^{-5} eV / K (8.617E-5 in Excel notation)
T	is Temperature in degrees Kelvin (Celsius degrees plus 273.15)
eV	means "Electron Volt"

The general case is to determine the component's service life operating at room temperature. Thereafter we are interested in the probable service life when used at a higher temperature. We use the comparative form of the Arrhenius Equation to estimate a service life acceleration factor:

Acceleration Factor = e **[(E_a / k) ($1/T_1$ - $1/T_2$)]

where T1 is the reference temperature (e.g. 25ºC / 298.15ºK)
and T2 is the actual use temperature.

The Activation Energy, E_a, is determined empirically. For the aluminum-copper alloys used in integrated circuit conductors the typical determined E_a values are 0.8ev to 1.0eV where 1.0eV is taken as the starting point for the analysis until enough statistical significant data is available to establish a more accurate estimate for E_a.

Applied to a fuse wearout experience with the Littelfuse R452 ½ Amp NANO fuse used in an over current and over temperature application
, the following acceleration factors are calculated assuming E_a = 1.0eV:

Operating Temp ºC	Operating Temp ºK	Acceleration Factor	Projected Service Life (1 / Acceleration Factor)
25	298.15	1	100.00%
45	318.15	12	8.65%
65	338.15	100	1.00%
85	358.15	679	0.15%
105	378.15	3,769	0.03%
125	398.15	17,607	0.01%

Discussion: These Acceleration Factors depend only on the activation energy, E_a, for the wearout processes specific to the materials and manufacturing methods used. This means that if E_a is the same or very similar for the Littelfuse R452 as for a comparable ½ Amp fuse from another manufacturer, then we can expect similar service life shortening at high operating temperature for the substitute fuse.

The punch line for all of the above =>

Operate all electronic components, including fuses, at lower temperatures to achieve a longer service life.

For completeness here is the same table of calculated Acceleration Factors for Ea= 0.8eV which is at the other end of the values observed for metalization systems in semiconductors:

Operating Temp ºC	**Operating Temp ºK**	**Acceleration Factor**	**Service Life Derate (1 / Acceleration Factor)**
25	**298.15**	**1**	**100.000%**
45	**318.15**	**7**	**14.121%**
65	**338.15**	**40**	**2.514%**
85	**358.15**	**184**	**0.543%**
105	**378.15**	**726**	**0.138%**
125	**398.15**	**2492**	**0.040%**

Note that Acceleration Factors are smaller for smaller E_a values.

Also note that merely raising the operating temperature from room temperature to 65ºC lowers the service life by a factor of 40 to 100 depending on the exact Ea. This means that a demonstrated room temperature 100,000 hour service life becomes just 2,500 hours or even 1,000 hours.

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