



HOT STUFF: MAXIMUM OPERATING TEMPERATURE

Often, you will find a column labeled as something like “Maximum Operating Temperature” or “Maximum Exposure Temperature” on a material data sheet.

Engineers who select materials would like to know this information, as it is important to figure out if a material can withstand the application temperature. Materials companies usually do not put this information on a data sheet, since *the maximum operating temperature depends on the potential failure modes, which in turn depend on several factors:*

- Application (what does the material have to do?)
- Time in service (how long does it need to function?)
- Environment (what external elements and forces will it have to withstand?)

Again, we have that phrase that non one likes to hear, “It depends”. The truth is that maximum operating temperature is much more of a **system property** than a **material property**.

The unfortunate reality of the engineering profession is that there are very few absolutes and most designs are a collection of optimized trade-offs. For example, and automotive engineer might ask, “How can I increase the safety of the people in and around this vehicle while improving speed, acceleration, handling (and potentially towing) capabilities; increasing range; enhancing comfort and entertainment; reducing fuel consumption and emissions; expanding room for people and cargo; enhancing consumer appeal; and then sell it for a satisfactory profit at a price that consumers would also find acceptable?” Somewhere along the line, one or more of those requirements will need to be dropped, or at least changed to “maintaining” or “not hurting too badly.”

The application is the most important factor. If this is a contact in a connector, the failure would be loss of signal integrity. This could be caused by loss of contact force due to **stress relaxation**, permanent set or fracture of the contacts, corrosion of the contact interface, loss of environmental seal, etc. A good number of these failure modes would be influenced by temperature, so *an increase in temperature increases the likelihood of the failure modes actually occurring.*



Time is also a major factor in determining the maximum operating temperature.

Stress relaxation, creep, **stress rupture**, corrosion, diffusion of base metal through plating, creep of corrosion products, and fatigue crack progression all increase with time. Most of these failure modes are accelerated

by higher temperatures. If the part only needs to survive a short time, these failure modes may not have a chance to develop. However, if the desired lifetime is extended, any one of these may occur. A material may be able to withstand a higher temperature for a shorter time, but longer term exposure would mean a lower permissible temperature. Since these failure modes are all cumulative, highly variable temperatures would make lifetime predictions problematic.



The operating environment may also play a role in determining the maximum operating temperature, since it influences the potential failure modes. Most forms of corrosion are accelerated by temperature, and the particular combination of application and

environment may produce a lower temperature failure mode. For example, if a part made from a susceptible steel alloy is put in a wet environment where it might be subjected to **pitting corrosion** or **crevice corrosion**, then the maximum operating temperature would be the **critical pitting temperature** or **critical crevice temperature**. Pitting or crevice corrosion will not occur below these respective temperatures. For some steel alloys, these temperatures can be below freezing. So, even if some of these alloys can withstand 500°C in a dry environment without significant loss of strength, they would not be suitable for submersion in water at room temperature.

I feel my temperature rising! – Which material properties permit a material to operate effectively at high temperatures.

- ▲ Maximum Operating Temperature
- ▲ System Property
- ▲ Material Property
- ▲ Stress Relaxation
- ▲ Stress Rupture
- ▲ Critical Pitting Temperature
- ▲ Critical Crevice Temperature
- ▲ Overaging
- ▲ Thermal runaway

The next issue of Technical Tidbits will discuss the measurement of electrical conductivity.

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Corrosion fatigue is a synergistic combination of corrosion and fatigue, where each process accelerates the other. Uniform corrosion, stress corrosion cracking, sulfide stress cracking, are also forms of corrosion accelerated by temperature. These and other forms of corrosion will be covered in greater detail in a future series of Technical Tidbits, since there is so much to say on this topic.



Higher temperatures also tend to reduce the strength and hardness of most materials. This loss of strength can increase permanent set and decrease contact force, which would increase the interface resistance of electrical contacts.

The decrease in effective hardness would also make parts more prone to wear. For parts such as bushings and bearings, higher temperatures can accelerate the degradation of lubricants that are vital for proper functioning, leading to faster wear-out. For age hardenable alloys, the increased temperature may actually lead to further age hardening in service. This can cause the metal to **overage**, reducing strength.

Current-carrying electrical contacts experience a temperature rise due to Joule heating (resistive) heating. The higher temperature reduces the electrical conductivity, although this is partially offset by an increase in thermal conductivity, per the Wiedemann-Franz law. If the excess heat that is generated can be removed quickly enough by the environment, then the contact will reach thermal

equilibrium. If not, the reducing conductivity and increasing temperature rise will feed upon each other in a feedback loop until the metal melts and the contact becomes a fuse, in a condition known as **thermal runaway**.

If I were to propose a generic definition of maximum operating temperature, it would go something like this: For a material operating in dry environment with minimal cycling, the maximum operating temperature is the temperature at which a material has lost 20% percentage of its room temperature yield strength or has lost 20% of its initial stress due to stress relaxation in 1000 hours whichever is lowest.

When designing for hot or harsh environments, you would need to take into account how the material's properties change with temperature, time, and the environment. A true maximum operating temperature would take into account the loss of the safety factor due to corrosion, reduction in yield strength or fatigue strength at the desired number of cycles (or reduction of fatigue life at the desired stress level), and stress relaxation over the desired operational lifetime. The best bet would be to ignore any published value for maximum operating temperature and obtain the corrosion, fatigue, elevated temperature, and stress relaxation test data and judge for yourself with the knowledge of the application and its environment.

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References:

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