

T_g - Glass Transition Temperature for Epoxies

WHAT

Glass Transition Temperature (T_g)

WHY

T_g is an important property of an epoxy, especially critical in product design.

The Glass Transition Temperature (T_g) is one of the most important properties of any epoxy and is the temperature region where the polymer transitions from a hard, glassy material to a soft, rubbery material. As epoxies are thermosetting materials and chemically cross-link during the curing process, the final cured epoxy material does not melt or reflow when heated (unlike thermoplastic materials), but undergoes a slight softening (phase change) at elevated temperatures.

What Exactly is T_g ?

The Glass Transition Temperature (T_g), not to be confused with melting point (T_m), is the temperature range where a thermosetting polymer changes from a hard, rigid or “glassy” state to a more pliable, compliant or “rubbery” state.

In actuality T_g is not a discrete thermodynamic transition, but a temperature range over which the mobility of the polymer chains increase significantly. The ultimate T_g is determined by a number of factors: the chemical structure of the epoxy resin, the type of hardener and the degree of cure.

T_g is usually measured using Differential Scanning Calorimetry (DSC): ASTM E1356, “Standard Test Method for Assignment of the Glass Transition Temperature by Differential Scanning Calorimetry”.

DSC Scan of a Typical Medium T_g Epoxy

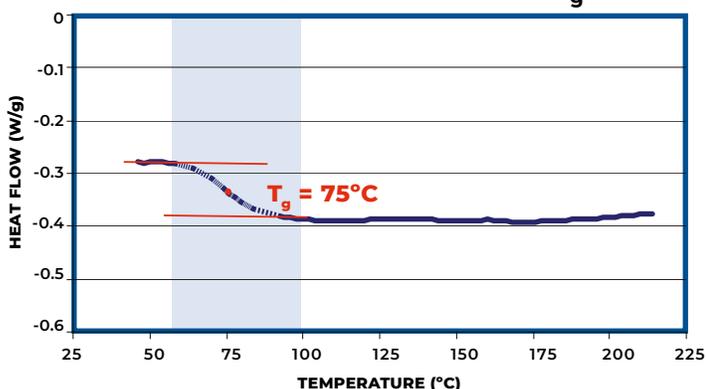


Figure 1

The format of the T_g scan is similar to that of a kinetic scan except that it is performed with a cured sample. Temperature is plotted on the X axis and the heat flow response on the Y axis (see figure 1)

As discussed previously, T_g is actually a temperature range, rather than a specific temperature. **The convention, however, is to report a single temperature** defined as the midpoint of the temperature range, bounded by the tangents to the two flat regions of the heat flow curve. For the epoxy material in the figure 1, the reported T_g would be 75°C.

T_g spans a temperature range, rather than occurring at a specific temperature, due to the cross-linked polymer chains having multiple degrees of freedom and modes of polymer chain movement in response to any applied thermal energy. The T_g value can also vary depending on its degree of cure. Generally, the reported T_g for a material is based on 100% conversion (full cure). For a more detailed explanation, see our *Epoxy Adhesive Application Guide*, pages 16-19.

Altering the T_g of an Epoxy

The T_g is strongly dependent on the cure schedule. Low temperature cures such as room temperature (RT) will result in the lowest possible T_g of all for that chemistry. Very high T_g values are not achievable by room temperature curing. If the same material is cured at an elevated temperature, a higher T_g will result. As an example an adhesive could have a T_g between 60°C and 110°C, based on the cure schedule. This is why it is important to maintaining tight temperature control in any production setting.

Additionally, the glass transition temperature (T_g) of epoxies can be significantly reduced by moisture absorption, a factor which should be considered when designing for humid applications.

Other T_g Considerations

Typically, adhesives with the highest T_g have the best heat resistance and therefore deliver the best tensile properties at high temperature. Unless there are significant exotherms associated with the cure process, as a general rule, a T_g cannot be significantly higher than the highest temperature seen during cure. For more information about the effect cure has on an epoxy, see "EPO-TEK® Cure Matters, Technical Aid."

Effects of T_g on:

Modulus > The basic relationship Modulus has to adhesives is: the higher the T_g , the higher the cross-linked density and the higher the modulus. As an epoxy rises above its T_g , the

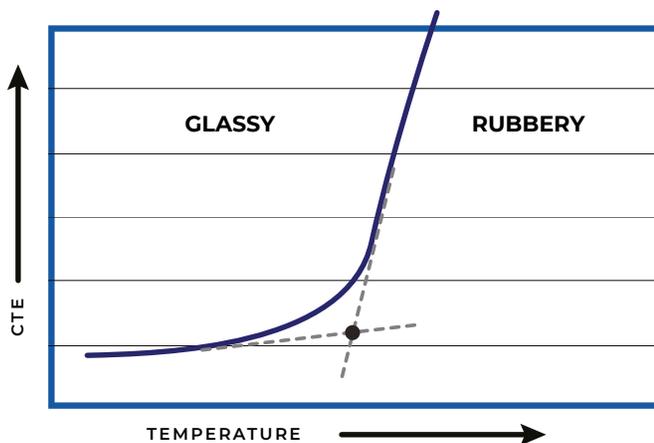
storage modulus drops. This is indicative of the change from a rigid to compliant state.

A high T_g along with a high storage modulus, results in a high stiffness which in most cases equates to a low percent elongation and poor energy dissipation when stressed at ambient temperatures. The modulus below the T_g has a primarily linear inverse relationship with temperature.

Lap Shear and Die Shear > Generally, as the temperature rises, the lap shear and die shear strengths of an epoxy will decrease. As an interesting side note, this effect is often employed as a means of removing cured adhesive.

As the epoxy becomes soft, cohesive failures become more prevalent. This then allows for two substrates to be more easily detached.

THERMO MECHANICAL ANALYSIS



Coefficient of Thermal Expansion (CTE)

Another important physical change that can occur with changing T_g in an adhesive, is the change in coefficient of thermal expansion (CTE).

As the temperature rises past the T_g , the adhesive will begin to soften and lose some tensile strength. It will also experience a rise in its CTE. Generally, there is a smooth transition between the two coefficients around the T_g .

You can also locate the T_g of a material by using a CTE curve. This is done by determining the intercept of the two curves, plotting Temperature versus Displacement.

Can I Use an Epoxy Above its T_g ?

Absolutely, unlike solder, an epoxy will not re-flow during a thermal cycle. A force produced by covalent bonds within the cured epoxy structure will cause the more compliant epoxy to revert back to its original shape when cooled below T_g . In many cases it may be advantageous to use an epoxy above its T_g , as the added compliance makes the bond more shock and vibration resistant. Additionally, the epoxy is also less likely to damage fragile components as a result of its lower rigidity.

For other useful tips, contact our Tech Service Group:

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