Thermal Shock Factors for Hexoloy® Silicon Carbide

CARBORUNDUM

Saint-Gobain Ceramics
Structural Ceramics

Introduction

An important factor to be considered when using ceramics in industrial applications is thermal shock. Thermal shock is a stress induced in a material because of temperature differences between the surface and the interior or between different regions of the component. These stresses can be high enough to cause failure of the component thus caution must be exercised when selecting materials, designs and operating conditions.

Factors in Thermal Shock

The peak thermal stress generated at the surface when the material is subjected to an infinite heat transfer rate is determined by the following formula;

$$\sigma_{th} = \frac{E\alpha\Delta T}{1 - \nu}$$

where: σ_{th} = thermal stress α = thermal stress ν = Poisson's ratio
E = elastic modulus ΔT = temperature difference

The formula shows that the peak thermal stress at the surface (tension during downward shock and compression on upward shock) increases as the elastic modulus and coefficient of thermal expansion increase and as the temperature differential increases.

When the heat transfer rate is finite, the analysis is much more complex. The peak thermal stress generated now becomes...

$$\sigma_{th} = \frac{E\alpha\Delta T}{1 - \nu} f(\beta)$$

where $f(\beta)$ is a function of the Biot modulus β(=rh/K) and;
r = characteristic dimension of component
h = heat transfer coefficient K = thermal conductivity

For small values of β, (<1), $f(\beta) = \beta$, which leads to the following equation for peak thermal stress;

$$\sigma_{th} = \frac{E\alpha\Delta T}{1 - \nu}\left(\frac{rh}{K}\right)$$

Thus, it can be seen from the above equation that the peak stress can be mitigated by selecting a material with high thermal conductivity or by designing a component with thin walls (consistent with any load bearing requirement.

The difficulty in the above analysis is that heat transfer coefficients for the medium of interest vary by orders of magnitude due to the nature of test or service and the material propertities may be a function of temperature. It needs to be emphasized that the only valid thermal shock test is with the actual component in the conditions encountered in service. Any other simplified test can be misleading and can only be used as a relative comparison between different materials.

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Recommendations for Hexoloy® SiC

- Using data from the Hexoloy® product brochure, a design engineer can calculate the stress generated by application temperature differentials. An example is shown at the bottom of the page.
- Designs for potential high temperature differential applications should incorporate thin and uniform walls. To reduce additioal stress concentrators, transitions and undercuts should be radiussed while all edges should be chamfered to avoid chipping.
- Our testing has also shown that finished grinding may induce additional stresses affecting thermal shock performance. Extreme applications may call for annealing ground components.

Conclusion

Design engineers can effectively use the best properties of silicon carbide, excellent corrosion and erosion resistance coupled with high thermal conductivity, in their application by balancing key parameters.

Thermal Shock

example: $\sigma_{th} = \frac{E\alpha\Delta T}{1 - \nu}$ for Hexoloy® @ application ΔT = 225˚C (437˚F)

where: σ_{th} = thermal stress

E = elastic modulus = 59×10^6 psi

α = coefficient of thermal expansion = 2.2×10^{-6} in/in ˚F

ΔT = temperature difference = 437˚

ν = Poisson's ratio = 0.14

or

σ_{th} = 66×10^3 psi

= 445 MPa

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