THERMAL PROPERTIES OF CERAMICS

The following thermal properties of ceramic materials are important in various design considerations:

- **Thermal conductivity**
- **Thermal expansion**
- **Heat capacity**
- **Thermal shock resistance**
- **Maximum service temperature**

Thermal Conductivity

Thermal Conductivity (λ) is amount of heat passing in unit time through unit surface in a direction normal to this surface when this transfer is driven by unite temperature gradient under steady state conditions.

Thermal conductivity may be expressed and calculated from the **Fourier's law**:

$$\Delta Q/ \Delta t = \lambda * S * \Delta T/ \Delta x$$

Where

Q -heat, passing through the surface **S**;
Δt - change in time;
λ - thermal conductivity;
S - surface area, normal to the heat transfer direction;
$\Delta T/\Delta x$-temperature gradient along **x** – direction of the heat transfer.
Fourier's law is analogue of the First Fick's law, describing diffusion in steady state.

In contrast to Metals Ceramics have low thermal conductivity due to Ionic-Covalent Bonding which does not form free electrons.
Compare:

λ of alumina = 47 BTU/(lb*ºF) (6.3 W/(m*K)).
λ of Al = 1600 BTU/(lb*ºF) (231 W/(m*K)).

Coefficient of Thermal Expansion

Thermal Expansion (**Coefficient of Thermal Expansion**) is relative increase in length per unite temperature rise:

$$\alpha = \Delta L/ (Lo\Delta T)$$

Where

α -coefficient of thermal expansion (**CTE**);
ΔL – length increase;
Lo – initial length;
ΔT – temperature rise.
Thermal expansion of ceramic materials is generally lower, than that of metals.

Compare:

CTE of SiC = 2.3 $^{o}F^{-1}$ (4.0 $^{o}C^{-1}$).
CTE of Al = 13 $^{o}F^{-1}$ (23 $^{o}C^{-1}$).

Specific Heat Capacity

Heat Capacity is amount of heat required to raise material temperature by one unit.
Specific Heat Capacity is amount of heat required to raise temperature of unit mass of material by one unit:
$c= \Delta Q/(m\Delta T)$
Where

c -specific heat capacity;
ΔQ – amount of heat;
m – material mass;
ΔT – temperature rise.
Specific Heat Capacity of ceramic materials is higher, than that of metals.

Compare:

"c" ofalumina = 0.203 BTU/(lb*ºF) (850 J/(kg*K)).
"c" ofsteel = 0.115 BTU/(lb*ºF) (481 J/(kg*K)).

Thermal Shock Resistance

Thermal Shock Resistance is an ability of material to withstand sharp changes in temperature.
If a ceramic material is rapidly cooled, its surface reaches the temperature of cooling environment and tends to contract (thermal contraction). Since the interior regions of the material are still hot, thermal contraction of the skin surface is impossible.

This leads to formation of tensile stress (**thermal stress**) in the skin. Such thermal stresses may cause cracks and consequent failure.
Thermal shock resistance of a material may be estimated in accordance to the formula:

$Rs = (\lambda*\sigma_F)/(\alpha*E)$
Where

Rs – thermal shock resistance;
λ - thermal conductivity;
σ_F – flexural strength
α -coefficient of thermal expansion (CTE);
E – modulus of elasticity.
Sensitivity of ceramic materials to thermal shock may be also determined by experimental method (Hasselmann Method).

In this method a specimen (flexural test specimen) is heated to a specified temperature and then quenched. The specimen cools rapidly by temperature ΔT (the difference between the specimen temperature before and after cooling).
After quenching the flexural strength of the quenched material is measured by standard flexure (bending) test.
The test results are plotted on the graph Strength vs. **ΔT**.
When **ΔT** reaches a certain value the specimen strength falls sharply. This value of **ΔT** is a parameter indicating thermal shock resistance of the material.
Some ceramic materials have very low coefficient of thermal expansion therefore their resistance to thermal shock is very high despite of low ductility (e.g. fused silica):
Rs of fused silica / **Rs** of soda-lime-silica glass = 45

Maximum Service Temperature

Ceramic materials retain their properties at elevated temperatures due to the strong ionic-covalent bonding.

Ceramics working at high temperature are called refractory ceramic materials.

Some Borides, carbides and nitrides, having melting temperature above 5500 ºF (3040 ºC), are used in high temperature applications up to 3300 ºF (1800 ºC)… 5430 ºF (3000 ºC).
Compare:

Scaling (oxidation) temperature of refractory stainless steel AISI 310 is 2100 ºF (1150 ºC).

Source : http://www.substech.com/dokuwiki/doku.php?id=thermal_properties_of_ceramics