

## **Lecture 1:**

### **1. Introduction to Advanced Ceramics:**

The term “ advanced ceramics ” (in Japan: fine ceramics) refers to ceramic materials that are:

- highly specialized by exploiting unique electric, magnetic, optical, mechanical, biological, and environmental properties;
- performing well under extreme conditions such as high temperature, high pressure, high stress, high radiation, and high corrosive exposure;
- predominantly inorganic – nonmetallic;
- relatively expensive, with properties and failure mechanisms not yet fully understood;
- capable of solving current manufacturing and use problems;
- high value - added products owing to their sophisticated processing technology;

In particular, advanced ceramics in terms of their high - temperature stability (up to 2500 ° C and beyond), high hardness, high corrosion resistance, low thermal expansion, and a variety of electrical properties ranging from insulators to semiconductors to highly conductive materials (Table 6.1 ). Although the fracture toughness and impact resistance of these materials are low compared to metals and some engineering plastics, modern processing technologies – and, in particular, the development of particulate - reinforced advanced ceramics – have led to the creation of transformation - toughened ceramics such as partially stabilized zirconia and modern nanostructured ceramics which provide materials that perform well, even under adverse mechanical conditions.

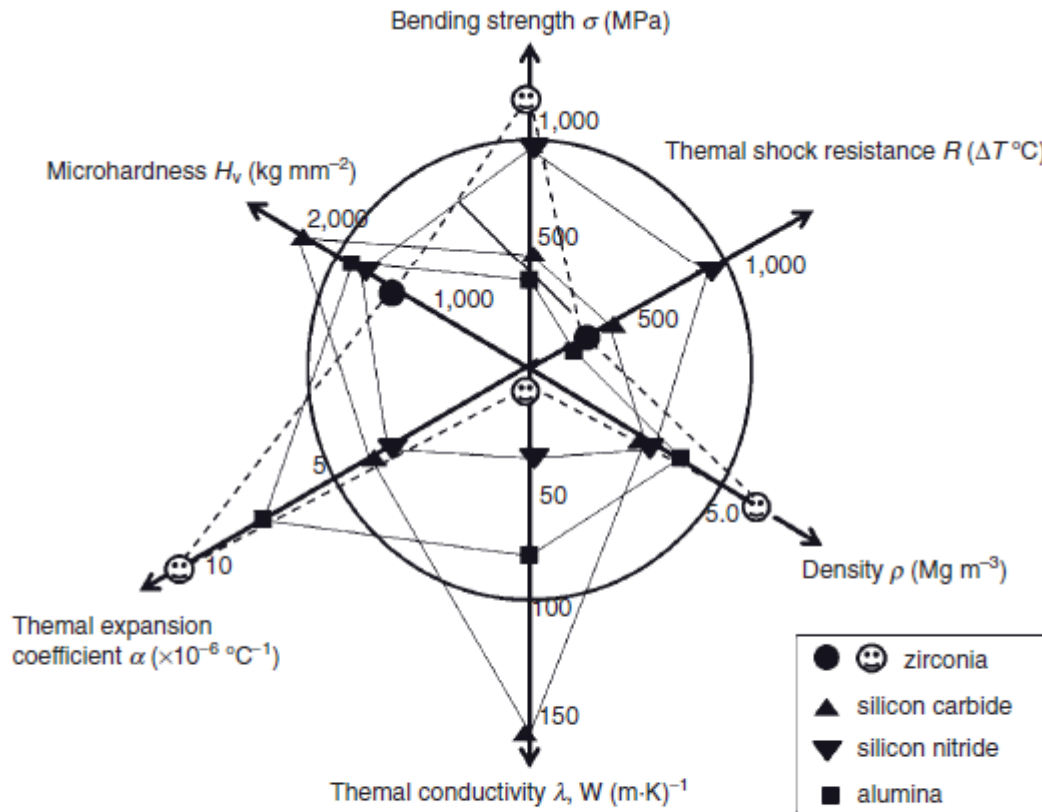
**Table 6.1** Comparison of important properties of metals, engineering plastics, and advanced ceramics.

Property	Metals	Engineering plastics	Advanced ceramics
Maximum temperature for continuous use (°C)			
Typical	1000	250	1200
Maximum	1500	350	2500
Hardness	Medium–high	Low–medium	High
Toughness			
Flexibility	Medium–high	High	Low
Impact resistance	High	Medium–high	Low
Corrosion resistance	Low–medium	Medium	High
Coefficient of thermal expansion	High	Medium	Low
Electrical properties	Conductive	Insulative to conductive (with fillers)	Insulative to conductive
Density	High	Low	Medium

One useful classification scheme divides advanced ceramics into *structural* and *functional* categories:

- *Structural advanced ceramics*: These are used for applications where a component of an engineering system is subjected to high mechanical, tribological, thermal, or chemical loads. Typical structural ceramics are alumina, partially and fully stabilized zirconia, cordierite, mullite, spinel, silicon nitride and SiAlONs, silicon carbide, boron nitride, titanium nitride, and titanium boride. The performance - application diagram (Figure 6.1 ) for zirconia, silicon carbide, silicon nitride and alumina shows that zirconia ceramics in high - temperature applications such as thermal barrier

coatings where high density, high bending strength, high thermal expansion and low thermal conductivity are required. Silicon carbide ceramics possess high thermal conductivity and high microhardness, but are deficient in strength and thermal shock resistance. Hence, the area of application of such ceramics is in heating elements for furnaces operating up to 1600 ° C in ambient atmospheres. Silicon nitride on the other hand shows a high thermal shock resistance, sufficient strength and hardness, and intermediate values of density and thermal conductivity which suggest applications in automotive engines and heat exchangers, as well as for ceramic cutting tools for the high – speed machining of hard metals. Lastly, alumina is hard and shows a rather high thermal expansion, but performs badly in terms of bending strength and thermal shock resistance. However, the requirements for superior abrasion and erosion resistance are not met by the austenitic steel, and this requires either a different base material or a resilient ceramic coating, such as tungsten carbide or chromium carbide.



**Figure 6.1** Performance–application diagram of four typical advanced structural ceramics: zirconia; silicon carbide; silicon nitride; and alumina. Owing to the dependency of the properties on processing

conditions, the values given are only tentative. Zirconia ceramics are characterized by a combination of useful properties unmatched by other oxide and nonoxide ceramics.

- *Functional advanced ceramics*: These, in contrast to structural ceramics, utilize microstructural effects localized within the volume, at grain boundaries or at the surfaces of conducting or nonconducting ceramics. Such effects encompass semiconducting, varistor, piezoelectric, pyroelectric, ferroelectric and superconducting properties. Novel ceramic technologies for the automotive industry include oxygen sensors, exhaust gas catalysts and fuel cells, as well as future ceramic gas turbines and compound diesel engines (Okada, 2008 ).
- *Bioceramics*: Bioceramic materials such as alumina and zirconia exploit exceptional structural stability in a highly corrosive body environment and hence

biological inertness, whereas hydroxyapatite and tricalcium phosphate provide functional osseoinductive and osseoconductive properties (Heimann, 2007 ).

Table 6.2 shows some application fields, typical components and some advanced ceramics solutions to fulfill the requirements for optimum component performance.

Higher - performance ceramics and their future role have been reviewed by Nicholson (1996).

**Table 6.2** Application fields, selected components and some advanced ceramics alternatives.

Application field	Component	Properties utilized	Advanced ceramics
Processing technology	Chemical apparatus	Corrosion resistance	Aluminum oxide
	Sliding rings	Wear resistance	Silicon carbide
	Thread guides		Titanium oxide
	Wire-drawing dies		Zirconium oxide
Shaping of materials	Cutting tools	Wear resistance	Aluminum oxide
	Grinding disks	Hardness	Silicon nitride
	Sand-blasting nozzles		Silicon carbide Boron carbide
High temperature	Burner nozzles	Heat resistance	Silicon nitride
	Welding nozzles	Corrosion resistance	Silicon carbide
	Heat exchanger	Heat conductivity	Aluminum oxide
	Crucibles		Carbon
	Heat pipes		Boron nitride
Engines	Valve seats	Heat resistance	Aluminum titanate
	Turbocharger	Corrosion resistance	Silicon carbide
	Gas turbine	Heat conductivity	Silicon nitride
	Catalyst support		Cordierite
	A-probe		Zirconium oxide
Electronics, electrical engineering, optics	Substrates	Special electrical and magnetic properties	Aluminum oxide
	Capacitors		Titanate perovskites
	Sensors		Ferrites
	Laser materials		
	Magnets		
Energy technology	Nuclear fuel	Radiation resistance	Uranium oxide
	Solid-state electrolyte	Ionic conductivity	Zirconium oxide $\beta$ -Aluminum oxide
Medical technology	Hip joints	Mechanical resistance	Aluminum oxide
	Bone replacement	Surface finish Biocompatibility	Calcium phosphate