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**Alpha alumina:**

Aluminum oxide, or alumina, crystallizes in the *corundum* structure (mineralogical term) to form sapphire monocrystals. We are referring here to white sapphire, like the one used for the manufacture of scratchproof “glasses” for watches, whereas in gemmology sapphire is the blue sapphire, which is alumina with a little  $Ti^{4+}$ ; ruby being alumina colored in red by  $Cr^{3+}$ . This is the *alpha* variety ( $Al_2O_3-\alpha$ ). The corundum structure belongs to the rhombohedral system. The crystal can be described as a compact hexagonal stacking of  $O^{2-}$  anions, in which the two-thirds of the octahedral interstices are occupied by  $Al^{3+}$  cations. We note that this reference to anions and cations insists rather misleadingly on the ionicity of the bond: it is considered that the alumina bond is ionic for two-thirds and covalent for the remaining third part. The strong ionic-covalent bonds and the rhombohedral structure combine to restrict the dislocation movement, the sapphire monocrystal remains brittle until very high temperatures and the glide slip is only possible beyond  $900^\circ C$ .

The plasticity of the polycrystal comes primarily from the effects of intergranular diffusion or flow of vitreous phases. These are mechanisms that depend on the purity of the material and whose occurrence temperature thresholds are lower than  $800^\circ C$  for impure aluminas and higher than  $1,100^\circ C$  for aluminas with purity exceeding 99%. Alumina is one of the best electrical insulators, hence its dielectric applications. Electric conduction depends primarily on impurities which act as acceptors (for example, Mg, Fe, Co, V or Ni) or as donors (for example, H, Ti, Si, Zr or Y), the balance between electronic and ionic contributions depending on the temperature and the partial pressure of oxygen. Among the impurities, sodium deserves a particular mention because the synthesis of alumina by the Bayer process brings into play sodic mediums; sodium aluminate ( $Na_2O \cdot 11Al_2O_3$ ), also called beta alumina, is an ionic conductor with very high conductivity, which is why this compound is envisaged for solid electrolyte applications. With an optical gap of about 9.9 eV,

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pure alumina is transparent in the visible and colorless domain. Like the electrical properties, the colored effects depend primarily on the impurities.

- ***Alumina ceramics:***

- 1. Structural applications of alumina:***

Alumina ceramics owe to the stability of this oxide and its strong atomic bonds their mechanical and thermal performances which imply – but do not necessarily combined in a single type of microstructure – high hardness, high moduli of elasticity, satisfactory mechanical strength, wear resistance and good tribological properties and refractivity. Giving accurate values would be useless because mechanical properties are sensitive properties which vary with the microstructure, and the hot properties depend highly on the temperature and chemical reactions when the environment is aggressive. To illustrate this point, a dense fine-grained alumina ceramic has a Young's modulus of  $\approx 400$  GPa (twice the modulus of steel), a Poisson's ratio of  $\approx 0.25$ , a Vickers hardness of 20 GPa and a mechanical bending strength  $\sigma_F$  of  $\approx 300$  to 500 MPa. For high temperature applications, in the absence of corrosion, sintered alumina pieces allow long duration uses, at temperatures that can exceed  $1,600^\circ\text{C}$ , but at stress levels that should not exceed a few MPa. Toughness at  $20^\circ\text{C}$  is equal to  $\approx 3.5$  MPa  $\text{m}^{1/2}$ , which is a respectable amount for a ceramic, but does not make alumina a tough material, especially when compared to metals. Ductility is modest. The coefficient of thermal expansion between  $20^\circ\text{C}$  and  $1,000^\circ\text{C}$  ( $\alpha_{20-1,000}$ ) is  $8.5 \cdot 10^{-6}$   $\text{K}^{-1}$ . This relatively high thermal expansion for a ceramic combines with a high Young's modulus in order to lower the first parameter of resistance to thermal shocks ( $R \approx \sigma_F / E \alpha$ ): alumina ceramics are not very resistant to thermal shocks and the residual stresses at the grain boundaries are reduced. We must be noted that we observe a poor creep resistance under substantial load. Alumina ceramics are best suited for mechanical uses or refractory uses, but they are not thermo mechanical materials.

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**- Mechanical Applications:**

1- *Abrasive Materials*: alumina is the most widely used abrasive and it depend on hardness, tribochemical effects, toughness and the morphology of the degradation facets of the abrasive grain, friction terms or thermal conductivity must also be considered. The industrial products are very varied [NOR 99] and range from free abrasives (powders or pastes) to agglomerated abrasives (grinding stones), passing through abrasives on flexible supports (“emery paper”). White and brown corundum are the usual products, but increased performances are obtained with globular alumina, alumina- zirconia with high toughness, or alumina obtained by precursor methods.

2- *Fillers*: Tabular alumina grains constitute the filler of many refractories, whether they are fashioned as bricks or not fashioned: castable refractory concretes whose binder is cement, itself with high alumina content

3- *Cutting Tools*: The tablets of alumina if necessary filled with titanium carbide to increase thermal conductivity or with zirconia to increase toughness, they can make impressive cutting speeds possible and they are adapted to the machining of hard metals or metals coated with oxidized layers.

4- *Tribological Applications*: they are at the heart of the structural uses of alumina. We are referring to thread-guides for textile industry, spray nozzles, rollers and other supports for the paper industry, extrusion dies and seals between parts which turn or slide on one another.

5- *Bulletproof Jackets, Protective Coatings of Helicopters or Tanks*: This must stop high speed projectiles ( $\approx 1,000 \text{ m s}^{-1}$ ) or the dart of melting metal at very high speed ( $\approx 10,000 \text{ m s}^{-1}$ ) from hollow charges. The mechanisms of shock resistance have not been clearly established, but they are primarily due to the fact that the shock wave is propagated at a speed higher ( $\approx 10,000 \text{ m s}^{-1}$ ) than the speed of growth of cracks ( $\approx 3,000 \text{ m s}^{-1}$ ). Therefore, the brittle fracture cannot follow the displacement of the shock wave and the “resistance” of ceramic then tends towards its theoretical value (about one-tenth of Young’s modulus). We need hard products, with high modulus and high mechanical strength under

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compression. Even if it is outclassed by ceramics like boron carbide and if light shieldings require polymers like *Kevlar*, alumina is still a good shielding material.

**- Refractory applications:**

The performances of cutting tools, thread guides and bearings, tape cartridges, prostheses or shieldings require dense and fine-grained microstructures. On the other hand, the high temperature applications of alumina demand a porous and coarse-grained material, except for the case where a need for sealing justifies the choice of dense materials. Also resistance to thermal shocks is better for a porous material and creep strength is improved by coarse grains. We must also mention lining and conveying equipment for furnaces (for the firing of ceramics, in particular), crucibles, protections of thermocouples, etc. The insulating tubes of laboratory electric furnaces illustrate such used beyond 1,400°C (in a horizontal position) or 1,700°C (in a vertical position). alumina is one of the basic compounds for the refractorist, in addition to other oxides (for example, MgO in the iron and steel industry and “AZS”: Al<sub>2</sub>O<sub>3</sub>-ZrO<sub>2</sub>-SiO<sub>2</sub> in glassmaking) and a few non-oxides (primarily carbons and graphite and silicon carbides).