

## SOURCES AND OCCURRENCES OF POROSITY AND MICROCRACKS

Porosity originates from the voids, which are created within the bulk. These pores are of two kinds, fig. 1; open and closed pores. The open or otherwise known as apparent porosity measures the fraction of open void volume to the material volume. The open pores are usually interconnected so that they provide passages through which gases can pass. If one maximizes the porosity for a given application, one can obtain a foam fig 2. Such foams are typically used for filtration or as a catalyst because of their high surface area

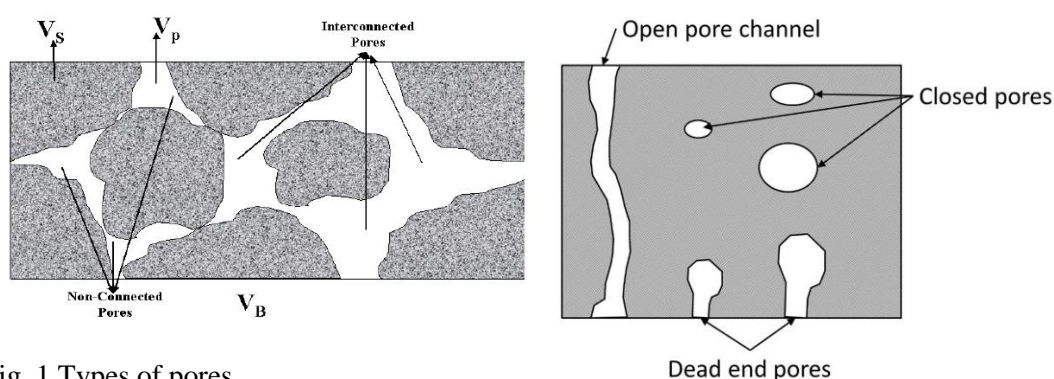
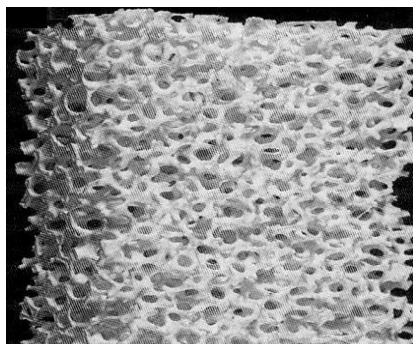


Fig. 1 Types of pores

Porosity is often detrimental to important properties such as elastic modulus, tensile strength, hardness or the thermal and electrical conductivities. The desired final properties depend on the final application of the ceramic. Porosity is obviously desirable in light-weight products, thermal insulation, catalyst, a high specific surface area is usually essential, supports, and filtration. Negative aspects include friability, loss of strength, undesirable fluid absorption etc.

There are several characteristics that will influence the porosity:

1. The connectivity of the pores: there exists open and closed porosity. In the first case, the pores communicate with the outside of the material, they can theoretically be filled with a fluid by immersion of the piece. In the case of closed porosity the pores are isolated inside the material.
2. The pore size: the pore size is important for the final properties as well as during the sintering as small pores are much more difficult to eliminate than large ones.
3. The shape of pores: the pores can have different shapes which influence their behavior. Open pores are typically thin, elongated and irregularly shaped. The closed pores are typically more equiaxed.
4. The distribution of the porosity: the distribution of the porosity can be of importance. For example during the production of ceramic layers, the porosity is not always uniform throughout the thickness of the layer.



**Fig 2 ceramic foam with high porosity**

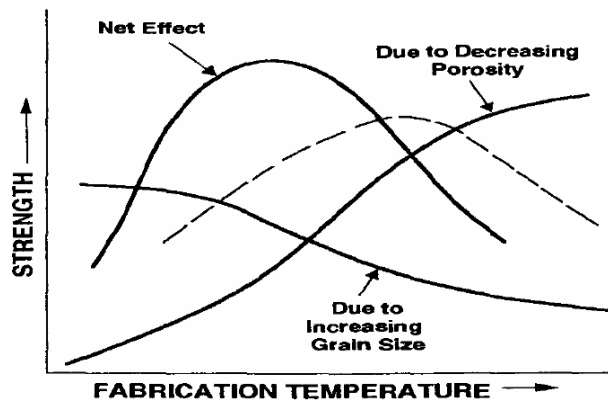
### **1.1 Intrinsic Sources (Other Than Sintering)**

The importance of porosity effects on properties which arise from its significant impact, as well as from its occurrence in most fabrication processes whether it is desired or not. Despite the frequent desire for no porosity for many applications, pores pervasively occur due to both **intrinsic** and **extrinsic** factors as well as physical and economical limitations. A basic step in understanding the effects of porosity is to be aware of its sources and occurrences.

Intrinsic limitations on reducing porosity were outlined for sintering (Fig. 3), where most or all pores start as open, intergranular pores and transition to closed, and even more in the transition to intergranular pores; the latter reflects a marked change in shape, i.e., rounded polyhedral to spherical pores.

#### ***Other sources of porosity,***

Both inter- and intergranular pores of similar scale can also be introduced by various processes, e.g., differential diffusion, dislocations (especially entangled ones from deformation)" stoichiometric changes, and phase changes due to reaction of constituents or impurities during, or after, sintering.



**Fig (3)**

### **1.2 Extrinsic Sources in Sintering**

There are other extrinsic aspects of processing that effect the amount and character of pores beyond the more intrinsic sources of porosity noted above, especially in sintering. Thus, more, and possibly somewhat larger pores commonly remain in sintered ceramics not only due to intrinsic effects, but also due to gases left in the originally open pores (e.g., due to firing in air rather than vacuum). Gases not soluble in the surrounding ceramic are entrapped in closed pores since they cannot be diffused out of the pore. Many other extrinsic sources of (commonly intergranular) pores exist, especially for sintered bodies. These other sources of pores, i.e., from the materials and forming operations used, contribute mainly to heterogeneity of the size, shape, and spatial distribution of the porosity.

The powders used for forming bodies often contribute larger, heterogeneous pores from heterogeneous particle sizes, shapes, or spatial distributions. Larger pores typically occur with agglomerates in the powder. Another extrinsic source in powder derived bodies are from foreign organic partials

### **1.3 Sources and Occurrence of Microcracks:-**

The first of three basic sources of microcracks on specimen surfaces is from transient, local impact on the specimen surface, e.g., from rain drops, ice, dust, particles of

sufficient sizes, velocities, and impact angles. The second, most prevalent and important source of such surface microcracks is from abrasive machining, which introduces two populations of cracks, one normal to the abrasive particle motion and the other parallel with it. The third source of microcracks, is from mismatched microstructural strains, especially from phase transformations (including crystallization of glasses) or thermal expansion of grains or particles in a body

## 2.1 HIERARCHY OF POROSITY IMPACTS ON PROPERTIES

There are three broad categories of porosity dependence of properties that increase in their complexity of dependence on porosity in a hierarchal fashion. there are properties that have no dependence on porosity; typically, these are those that depend only on the local atomic bonding and are not affected by pores. Thus, properties such as lattice parameter and derivative properties such as unit cell volume fall in this first category, as do melting and boiling temperatures, ablation energy, and emissivity. An important extension of these atom bonding determined properties to macroscopic behavior that does not depend on porosity is **thermal expansion**.

The second category consists of those properties dependent only on the amount, and not the character, of porosity. This category consists of properties dependent only on the mass in a given volume and not the specifics, i.e., the microstructure, of its distribution within that volume. This includes density, heat capacity (per volume), and much dielectric constant data. Such properties follow a rule of mixtures relation for the volume fractions of the pore phase (P) and the solid phase (I - P):

$$X = X_s (I - P) + X_p P$$

where X = the property of the body,  $X_s$  = the solid property (i.e., at  $P = 0$ ), and  $X_p$  = the property of the pore phase (often zero, but not always, e.g., typically about 1 for the refractive index and dielectric constant).

**The third**, most complex and important category of the porosity dependence consists of those properties dependent on both the amount as well as the character of the porosity. **Three important sub-sets of this are :**

- A) properties determined only by flux or stress transmission through the solid but not through the pore, phase,
- B) properties determined only by flux through the pore phase (e.g., filtration), and
- C) properties dependent on transmission through both the solid and pore phases.

It is important to note that some properties can change categories with the nature of the porosity or the conditions.

The dielectric constant of bodies with substantial fine porosity, high dielectric constant material, or both, deviate below the rule of mixtures relation (apparently when surface charges on the pores becomes significant) moving it from Category II to Category III. At lower temperatures and finer, closed porosity where convective and radiative heat transfer across and between pores are insignificant, thermal conductivity falls in Category III A; however, as temperature and the size, amount, and openness of pores increases, thermal conductivity transitions to Category III C, and at high temperatures and porosity can approach Category III B due to thermal transport by radiation. Some properties are difficult to categorize, e.g., dielectric breakdown where the stress is in the solid phase, but much of the actual breakdown may occur via the pore phase.

So Flaws (pores & cracks) in the material added during processing, final machining, or testing, or while in service.