Corrosion of dental ceramic materials

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Corrosion of materials

In general the environment will attack a ceramic, forming a reaction product.

- The corrosion of a solid crystalline material by a liquid can occur through the formation of an interface or reaction product formed between the solid crystalline material and the solvent.

- The driving force for dissolution is a combination of both the interface chemical reaction and the interdiffusion of the products and reactants.

- The solubility of materials in liquids can be obtained from phase diagrams, which give the saturation composition at a given temperature.

Noyes-Nernst equation represents the flux density across the solute interface:

$$V\frac{dC_\infty}{dt} = jA = \left(\frac{D}{\delta *}\right)\left(C_{sat} - C_\infty\right)A$$

V = volume of solution,
C_∞ = concentration in the bulk,
C_{sat} = saturation concentration,
A = area of interface,
D = diffusion coefficient,
δ^* = boundary layer thickness, and
t = time.

By including the surface reaction rate constant, *K*, Berthoud 1912 derived the following equation:

$$j = \frac{K}{\left[1 + \left(\frac{K\delta *}{D}\right)\right]}\left(C_{sat} - C_\infty\right)$$

Corrosion of ceramic materials

In case of mineral, especially silicate ceramics with containing alkalies and alkaline earths, the low density of cross-links tend to dissolve congruently and rapidly, while minerals with a high density of cross-links dissolve incongruently producing a leached surface layer.

- Incongruent dissolution result form the hydration, hydrolysis, and ion-exchange.
- Hydration is more prevalent in materials with low degree of covalent character to the cross-links and a structure that allows water penetration into the structure.

The dissolution of minerals, and actually any ceramic, is dependent upon the *p*H of the water.

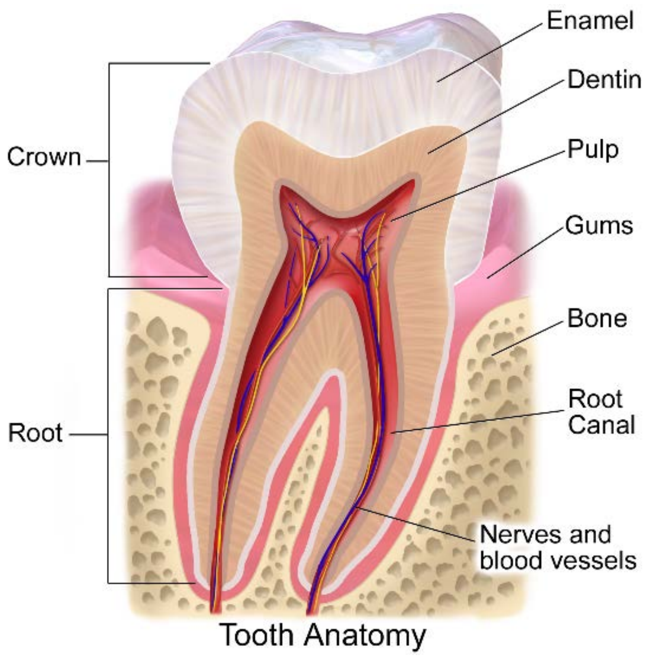
$$\mathrm{Mineral\ A} + \mathrm{nH}^* + \mathrm{mH_2O} \leftrightarrow \mathrm{Mineral\ B} + \mathrm{qM}^*$$

Equilibrium constant $$k = \left(\frac{[M^+]^q}{[H^+]^n [H_2O]^m} \right)$$

$$\mathrm{Rate} = \mathrm{k} = \frac{dV_{pit}}{dt}$$

where: V_{pit} = volume loss of etch pits after time t.

Corrosion of human tooth



- Enamel's primary mineral is hydroxyapatite (HA), which is a crystalline calcium phosphate [$Ca_{10}(PO_4)_6(OH)_2$]. (96% inorganic, with organic materials, and water)
- Dentin is a mineralized connective tissue with an organic matrix of collagenous proteins. (70% inorganic, 20% organic materials, and 10% water)
- Pulp is the central part of the tooth filled with soft connective tissue

The process of degradation of ceramics in the human mouth is quite complex, involving dissolution in salvia and the various physicochemical reactions caused by food, chewing, and bacteria.

Corrosion of human tooth

- Acidic foods (e.g., soft drinks with *p*H of 4–5) and bacteria provide the most important form of chemical attack upon tooth enamel.

Process of degradation of ceramics in the human mouth	Dissolution and consumption of tooth enamel
Acidic beverage (pH = 4-5)	0.1 nm/s (3 mm/yr)
Distilled water (pH = 7)	0.013 nm/s (0.4 mm/yr)
Food and drink consumption	0.3 to 2.0 mg/day

- The maximum material loss was mostly from grain boundaries of the hydroxylapatite (HA, [$Ca_{10}(PO_4)_6(OH)_2$]) because grain boundaries often contain a more soluble second phase.

- Natural dental enamel is composed of about 96 wt% HA and contains about 4 to 6% carbonate. Those carbonate content increased with age. This increased carbonate decreased the a-lattice parameter with no significant change to the c-lattice parameter.
  In addition HA crystallinity decreased with age.

Corrosion of dental ceramic materials

- **Food and drink consumption : 0.3 to 2.0 mg/day**

<Alumina and Zirconia>

- Although alumina and zirconia are considered essentially inert bioceramics, **they are truly not 100% inert.**

LS2 (Lithium disilicate)
→ 0.14 mg/cm^2 day
at pH=2,7 and 10 for 1 for 30 days

<Glass-ceramics>

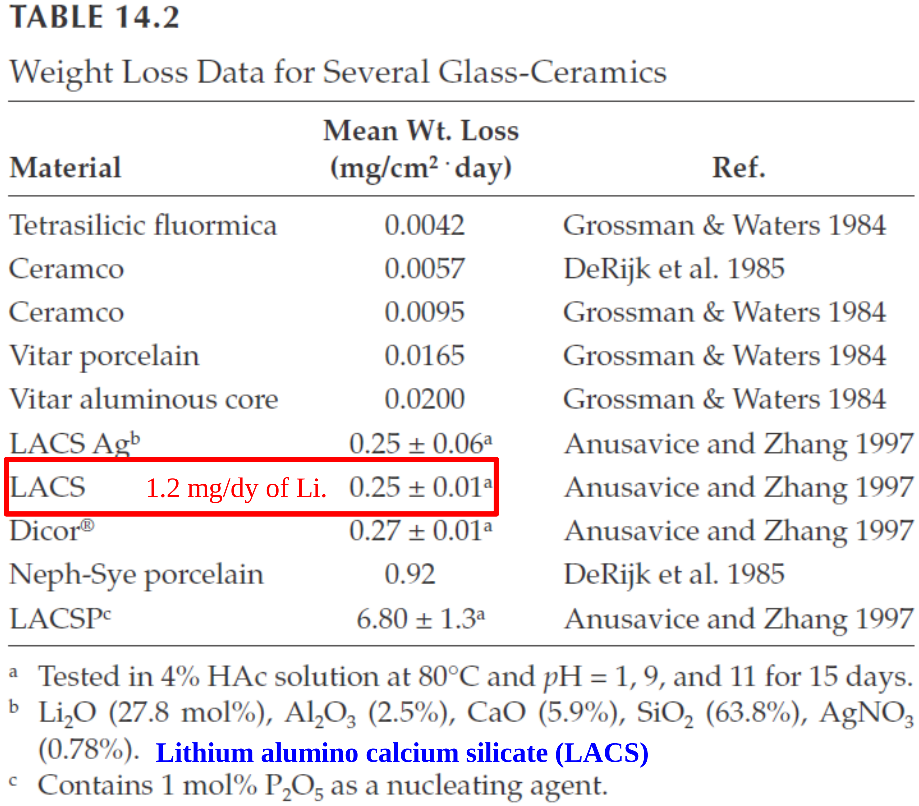


TABLE 14.2

Weight Loss Data for Several Glass-Ceramics

Material	**Mean Wt. Loss (mg/cm^2 · day)**	**Ref.**
Tetrasilicic fluormica	0.0042	Grossman & Waters 1984
Ceramco	0.0057	DeRijk et al. 1985
Ceramco	0.0095	Grossman & Waters 1984
Vitar porcelain	0.0165	Grossman & Waters 1984
Vitar aluminous core	0.0200	Grossman & Waters 1984
LACS Ag[b]	0.25 ± 0.06[a]	Anusavice and Zhang 1997
LACS 1.2 mg/dy of Li.	0.25 ± 0.01[a]	Anusavice and Zhang 1997
Dicor®	0.27 ± 0.01[a]	Anusavice and Zhang 1997
Neph-Sye porcelain	0.92	DeRijk et al. 1985
LACSP[c]	6.80 ± 1.3[a]	Anusavice and Zhang 1997

[a] Tested in 4% HAc solution at 80°C and pH = 1, 9, and 11 for 15 days.

[b] Li_2O (27.8 mol%), Al_2O_3 (2.5%), CaO (5.9%), SiO_2 (63.8%), $AgNO_3$ (0.78%). **Lithium alumino calcium silicate (LACS)**

[c] Contains 1 mol% P_2O_5 as a nucleating agent.

Reference

1. Corrosion of ceramic materials, Ronald A. McCauley, 3rd
2. Corrosion of ceramic and composite materials, Ronald A. McCauley
3. Surface Degradation of Dental Ceramics as a Function of Environmental pH, J Dent Res. 92(5) (2013) 467–471.