

### **Bioactive glass-ceramics**

They are polycrystalline ceramics made by controlled crystallization of glasses using heat treatment resulting in the nucleation and growth of crystal phases within the glass. The resulting glass-ceramic consists of at least one glass phase and one crystal phase and superior mechanical properties to those of the base glass from which it was formed. The reason for this is that, unlike glass which is amorphous, crystalline ceramics contain structural discontinuities or grain boundaries at points where the crystals meet, which act as an impediment for fracture propagation by causing deflection, branching, or splitting of cracks that lead to increase the fracture toughness and make glass-ceramics more suitable than glass for bone load bearing applications.

The nucleation of glass is carried out at temperatures much lower than the melting or glass transition temperature, in order to obtain a more crystallized material, the glass is further heated to a temperature at which maximum crystal growth can be attained without deformation of product or phase transformation within the crystalline phases or redissolution of some of the phases. Crystallization is usually more than 90% complete when grain sizes are 0.1 to 1  $\mu\text{m}$ , which are much smaller than in conventional ceramics. Figure 4 is a schematic representation of the temperature–time cycle for a glass-ceramic.

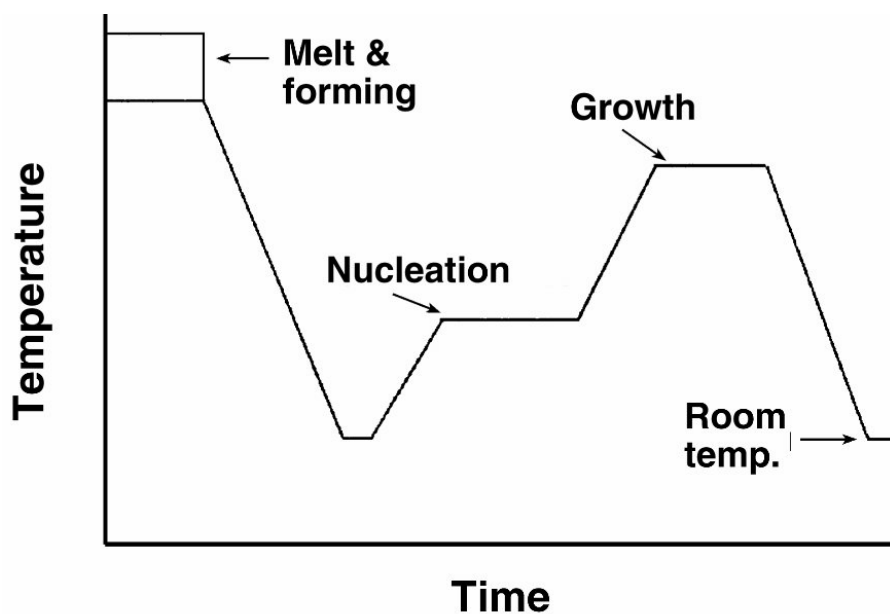


Fig.4 Temperature–time cycle for a glass-ceramic.

There are many chemical compositions of glass-ceramics that can be used as a filler and for direct attachment to tissue.

The composition of **Ceravital®** is similar to Bioglass® in  $\text{SiO}_2$  content but differs somewhat as far as the other components.  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ , and  $\text{Ta}_2\text{O}_5$  are present in Ceravital® in order to control the dissolution rate of the ceramic. The mixtures are melted in a (platinum) crucible at  $1500^\circ\text{C}$  for 3 hr, annealed, and then cooled. The nucleation and crystallization temperatures are  $680^\circ\text{C}$  and  $750^\circ\text{C}$ . Both processes should proceed for 24 hr.

Due to the controlled grain size and improved resistance to surface damage, glass-ceramics can have at least double the tensile strength (from about 100 to 200 MPa), the modulus of elasticity is on the order of 100 GPa, and the compressive strength is about five times the tensile strength,

**Apatite-Wollastonite (A-W)** glass-ceramic is now produced under the trade name of Cerabone®. They are the most widely used two-phase glass-ceramics and are based on the  $\text{SiO}_2\text{-P}_2\text{O}_5\text{-CaO-MgO}$  system with a very small amount of  $\text{CaF}_2$ . The material contains  $\beta$ -wollastonite ( $\text{CaO.SiO}_2$ ) and crystalline oxyfluorapatite, its high strength being attributed to the presence of the chain phase wollastonite.

**Apatite-mullite (A-M)** glass-ceramics are based on the  $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-P}_2\text{O}_5\text{-CaO-CaF}_2$  system, which crystallizes to form an apatite phase (fluorapatite) and mullite ( $3\text{Al}_2\text{O}_3.2\text{SiO}_2$ ) upon heating. The microstructure of this glass-ceramic consists of interlocking apatite and mullite crystals that have a high length to diameter aspect ratio. During fracture these needle-like crystals are pulled out resulting in high fracture toughness. As a result, apatite-mullite glass-ceramics have achieved bend strength in excess of 250 MPa and fracture toughness of  $2.5 \text{ MPa.m}^{1/2}$ .