**Mechanical Properties of Biomaterials:**

The mechanical properties of a biomaterial can best be described by its modulus of elasticity, ultimate tensile strength, elongation to failure, and fracture toughness.

* Modulus of elasticity describes the stiffness of the material and is usually obtained from the slope of a stress-strain diagram.
* Ultimate tensile strength describes the ability of the material to withstand a load before it fails.
* Elongation to failure describes how much strain the material can bear before it fails.
* Fracture toughness is an important measurement of the material's resistance to crack propagation.

Figures 1 (a) to (d) show the comparisons amongst different classes of biomaterial with respect to the four properties mentioned above. It can be seen that metals are generally very stiff and have high fracture toughness. In sharp contrast to the metals are the polymers, which have low stiffness and fracture toughness. However the polymers have high elongation to failure. The high stiffness of metals, on the other hand, can be a disadvantage since this can give rise to "stress shielding" in bone fracture repair. Stress shielding is a phenomenon where bone loss occurs when a stiffer material is placed over the bone. Bone responds to stresses during the healing process. Since the stress is practically shielded from the bone, the density of the bone underneath the stiffer material decreases as a result.



a



b



c

d



Figure 1 (a) Comparison of modulus of elasticity of biomaterials. Note the very high values for ceramics and metals. (b) Comparison of ultimate tensile strengths of biomaterials. Note the exceptionally high values for metals which make the metals an ideal choice for load bearing applications.(c) Comparison of elongation at failure of biomaterials. Note that polymers have exceptional elongation as compared to other materials. This is a measure of their high ductility. (d) Comparison of fracture toughness of biomaterials relative to the log (Young's modulus) with bone as the reference. Note that the fracture toughness values of metals are generally several orders of magnitude higher than those of the other materials. The Young's modulus is also much higher than that of bone, giving rise to stress shielding.

**1. Effects of Processing on Properties of Biomaterials:**

1. 1 Effect of Post Processing and Grain Size:

Numerous properties of biomaterials can be improved by processing techniques. Figure 2 shows the fatigue strengths of some commonly used metals. It can be seen that the fatigue strengths of forged 316L stainless steel and cobalt–chromium are significantly higher than in their cast state. The increase in fatigue strength can be attributed to the large compressive force applied on the surface of the metal during the forging process, as well as due to grain refinement. How grain refinement leads to an increase in fatigue strength can he understood from the Hall–Petch equation. The equation states that the yield strength of a material (σyD) is inversely proportional to the square root of the grain size (d):

where **k** is a constant



Figure 2 Fatigue strengths (in air) of common alloys used as implants. Note the effect of post processing conditions to improve fatigue strength .

For many years in the steel industry, the subject of grain refinement has been intensely pursued to help improve the yield strength of steel. Nanograin structures have been produced via severe plastic deformation with remarkable success . The other common route is to use powder metallurgy where ultra-fine particles are consolidated, compacted, and sintered at elevated temperature. Figure 2 shows that after cobalt–chromium alloy is subjected to hot isostatic pressing (H.I.P.), its fatigue strength is almost double than that in the cast state .The use of isostatic pressure also helps to reduce defects —such as voids — in the alloy.

Brittle materials — such as bioceramics — are sensitive to stress concentrations which exist around pre-existing defects, such as pores, scratches, or cracks. Under an applied tensile stress, σ, the stresses at the tip of a crack can be described by the stress intensity factor K, which is given as follows:

where **a** is the defect size and **Y** a geometry factor related to the crack

Fast fracture occurs when **K** becomes larger than the fracture toughness, KIC. Fracture strength, σs, can then be given by:

Composite processing by combining two or more phases is one route to produce enhanced properties of biomaterials. Another approach to obtain improved strength and reliability is to refine ceramic processing to produce homogeneous components with a defect size as small as possible. This can be done by refining powder processing to eliminate microstructural flaws. Ceramics such as alumina has been used for femoral heads in total hip replacements (THR) as an alternative to metal. This is because the wear rate in a ceramic-polyethylene combination was shown to be reduced significantly. However, reports of in vivo brittle fractures of ceramics due to delayed slow crack growth had brought about a new development in using composites of alumina and zirconia. The influence of processing conditions (such as those in colloidal processing) on the microstructures development of zirconia-toughened alumina composites, and the effect of these microstructures on the mechanical properties of alumina—zirconia composites. They have demonstrated that by using colloidal processing, microstructure refinement has brought about a significant improvement in the fracture toughness of ceramics (see Table 1).

Table 1 Fracture threshold, toughness and hardness of alumina, zirconia, and alumina–zirconia composites