Mechanical properties of biomaterials

For any material to be classified for biomedical application there are many requirements must be met , one of these requirement is the material should be mechanically sound; for the replacement of load bearing structures, the material should possess equivalent or greater mechanical stability to ensure high reliability of the graft.

The physical properties of ceramics depend on their microstructure, which can be characterized in terms of the number and types of phases present, the relative amount of each, and the size, shape, and orientation of each phase.

Elastic Modulus

Elastic modulus is simply defined as the ratio of stress to strain within the proportional limit. Physically, it represents the stiffness of a material within the elastic range when tensile or compressive load are applied. It is clinically important because it indicates the selected biomaterial has similar deformable properties with the material it is going to replace. These force-bearing materials require high elastic modulus with low deflection. As the elastic modulus of material increases fracture resistance decreases. The Elastic modulus of a material is generally calculated by bending test because deflection can be easily measured in this case as compared to very small elongation in compressive or tensile load. However, biomaterials (for bone replacement) are usually porous and the sizes of the samples are small. Therefore, nanoindentation test is used to determine the elastic modulus of these materials. This method has high precision and convenient for micro scale samples. Another method of elastic modulus measurement is non-destructive method such as laser ultrasonic technique. It is also clinically very good method because of its simplicity and repeatability since materials are not destroyed. An ultrasonic technique has been developed for measuring the elastic moduli of bioceramic coatings applied to titanium orthopaedic implants.

Hardness

Hardness is a measure of plastic deformation and is defined as the force per unit area of indentation or penetration, Hardness is one of the most important parameters for comparing properties of materials. It is used for finding the suitability of the clinical use of biomaterials and had the positive effect on the mechanical degradation resistance .Higher hardness resulted in less abrasion. Biomaterial hardness is desirable as equal to bone hardness. Because, if it more than the biomaterial then it penetrate in the bone. As above said biomaterials sample are very small therefore, micro and nano scale hardness test (Diamond Knoop and Vickers indenters) are used. It is rather difficult to use a traditional hardness test for ceramics and glasses due to their nonyielding nature (no

plastic deformation). The addition of 0.2wt.% of Li to hydroxyapatite (HA) can increase the microhardness and produces a fine microstructure.

Fracture strength

Strength of materials is defined as the maximum stresses can be endured before fracture occurs. Strength of biomaterials (bioceramics) is important mechanical property because they are brittle in nature. In the brittle material (bioceramics) crack are easily propagate in tensile load therefore, it is more critical than the compressive load. A number of method are available to determine the tensile strength of material such as bending flexural test, biaxial flexural strength test, weibull approach. In bioceramics, flaws influence the reliability and strength of the biomaterial during the implantation and fabrication. There are number of way that can be produce flaws in the bioceramics such as thermal sintering and heating. In short bioceramics need not very high strength, but, more important is high reliability.

The strength of brittle materials depends on the size of flaws distributed throughout the material. According to Griffith's theory of fracture in tension، the largest flaw or crack will contribute the most to the failure of a material. Strength also depends on the volume of a specimen since flaw size is limited to the size of the specimen's cross-section. Therefore, the smaller the specimen (e.g., fibers), the higher the fracture strength. Porosity of implanted bioceramic has a tremendous influence on the physical properties, increasing porosity and pore size means increasing the relative void volume and decreasing density; this leads to a reduction in mechanical properties and lowers the overall strength of bioceramic. In addition, it is difficult to avoid formation of pores during processing of materials. The nonyielding nature of brittle materials like ceramics is the main reason for the increased stress

To use of ceramic as self-standing implants that are able to withstand tensile stresses is a primary engineering design objective. Four general approaches have been used to achieve this objective: 1) use of the bioactive ceramic as a coating on a metal or ceramic substrate. 2) strengthening of the ceramic, such as via crystallization of glass. 3) use of fracture mechanics as a design approach and 4) reinforcing of the ceramic with a second phase. Hydroxyapatite and other calcium phosphates bioceramics are important for hard tissue repair because of their similarity to the minerals in natural bone, and their excellent biocompatibility and bioactivity but they have poor fatigue resistance and strength. Hence, bioinert ceramic oxides having high strength are used to enhance the densification and the mechanical properties of them. Alumina has a high strength; therefor β-TCP is introduced with different percentages in the alumina matrix for biomedical applications in order to improve the biocompatibility of alumina and the strength of tricalcium phosphate effectively.

Fracture toughness

Fracture toughness is required to alter the crack propagation in ceramics. It is help to evaluate the serviceability, performance and long term clinical success of biomaterial. It is reported that the high fracture toughness material improved clinical performance and reliability as compare to low fracture toughness. It can be measured by many methods e.g. indentation fracture, indentation strength, single edge notched beam, single edge pre cracked beam and double cantilever beam.

Hydroxyapatite (HA) has a fracture toughness of 1 MPa.m$^{1/2}$, whereas human bone has a fracture toughness of 2-12 MPa.m$^{1/2}$. One of the ways to improve the mechanical properties is to improve the densification of HA through the addition (5wt.%) of k_2CO_3 , Na_2CO_3. The addition of partially stabilized zirconia (PSZ)to HA can be used to increase the fracture toughness. The surface energy of the PSZ-HA was not significantly different from HA alone. This suggests that the PSZ-HA composite could be biocompatible because of the similarity of the surface with HA.