Acoustical and Porocimicromechanical Characterization of Titanium Scaffolds for Biomedical Applications


* Vienna University of Technology, Austria ** Fraunhofer Institute IFAM, Bremen, Germany *** Warsaw University of Technology, Poland

General

Bone biomaterials should match the original properties of bone as precisely as possible, in order to preserve standard physiological stress fields around the implant. Precise determination of these stress fields requires profound knowledge of the 3D material properties of both bone and bone replacement materials, such as titanium. We here present a corresponding experimental campaign on dense and porous titanium samples, the latter having recently been proposed [1] to as enhance bone ingrowth characteristics.

Acknowledgment:

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Literature:

Poro-mechanics - prediction of mechanical properties from porosity / microstructure

Processing

Dense (low porosity) and porous (high porosity) cylindrical samples of diameter 9 mm and height 14 mm were produced by powder metallurgical process, involving the use of organic space holders (polymers spheres of para-formaldehyde with mean diameters of 500 microns).

1. Mixing of metal powder and polymer space holder material, together with process aiding chemicals dissolved in water or organic solvent, ensuring satisfactory metal-polymer bonding
2. Axial pressing of mixture in a powder press
3. Removal of polymer / bonding agent through a catalytic process
4. Sintering in a high vacuum atmosphere

The upper figures show the produced samples with two different porosities (Titanium dense and porous). The lower figures show a micrograph of the center of a dense Titanium sample.

Acoustical testing - elasticity

Employing ultrasonic transducers (see right image) with frequencies of 0.1, 5 and 10 MHz, a pulser-receiver (see left image) and an oscilloscope, four dense and four porous Titanium cylindrical specimens were characterized by means of the transmission through technique. The frequency f of the ultrasonic wave determines the wavelength $\lambda = \nu / f$, being much larger than a representative volume element (RVE), which is, by definition subjected to homogenous stresses (see figure in Micromechanics Box). This material characteristic length $\lambda_{\text{MPP}}$ contains even smaller inhomogeneities of size $d \ll \lambda_{\text{MPP}}$ so that $d \ll \lambda_{\text{MPP}} \ll \lambda$. (See Table below for measurements).

If the wavelength is much smaller than the diameter of the specimen, longitudinal and transversal ultrasonic bulk waves propagate, with phase velocities $v_1$ and $v_2$, giving access to isotropic stiffness tensor components as well as to technical constants Young’s modulus $E$ and Poisson ratios $\nu$ of the material with $\nu \ll \lambda$ [3].

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Mechanical testing - strength

Experimental setup for uniaxial and triaxial tests at TU Vienna:
(a) testing machine
(b) pressure control
(c) 150 bar triaxial cell
(d) fixing of specimen
(1) specimen
(2) plasticine
(3) upper die
(4) lower die

For resulting strength data, see figures in Micromechanics Box.