Synchrotron radiation Investigations of Hydroxyapatite in Sheep Bone at the interface with Implant

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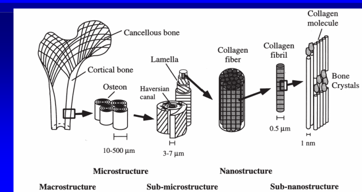
Abstract:

Bone is a composite material in which two phases are associated, a mineral phase, formed by crystals of hexagonal hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$ (HAp), and an organic phase, collagen. The c-axes of HAp and the collagen fibres are preferentially oriented in the direction of the stresses which the bones need to withstand. We probed the samples with a spatial resolution of 350 µm on ID15B at ESRF in order to investigate the preferred orientation of HAp crystallites in sheep tibia at the interface with implant and calculate the pole figures from the orientation distribution function.

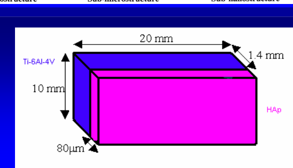
2. Structure of the bone

the bone occurs with two principal structural forms: cortical, or compact bone, which form a dense matrix, and spongy bone. Compact bone exists in the axes of long bones and spongy bone in the ends of long bones, inside the vertebral bones of the spine, and compressed between the layers of compact bone in the skeleton's plate structures. We used in this work cortical bone.
HAp crystallises in the hexagonal system and its unit cell parameters are a=9.4 Å and c=6.8 Å, its space group is $P6_3/m$.



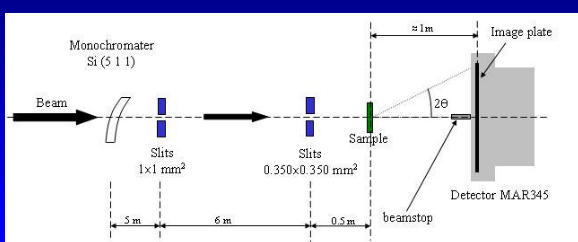
3. Materials and methods

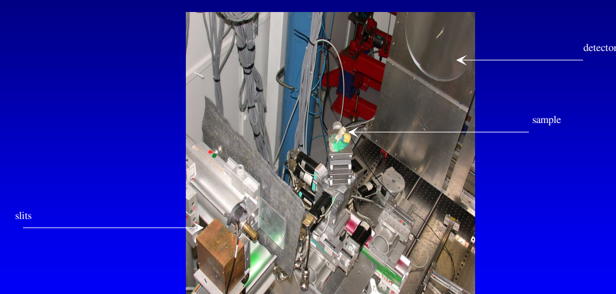
We used in this study bone material from one sheep with two implants, Ti-6Al-4V, (20 mm x 10 mm x 1.4mm) inserted in its left and right tibia bones and extracted 60 days after implantation , the implant having one face coated, the other not.



4. ID15B at ESRF

- ID15B at the ESRF is a high-energy beamline (88,4 keV), equipped with a diffraction setup for the studies of single crystals, powders and amorphous materials with area detectors to collect many reflections simultaneously.

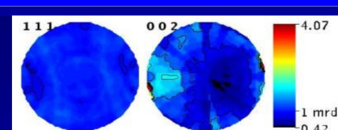


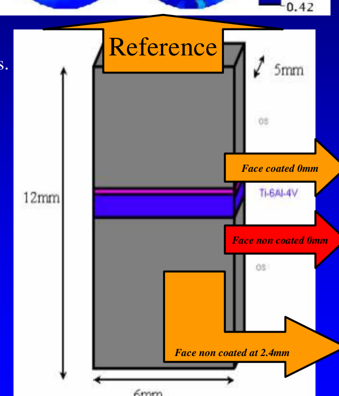


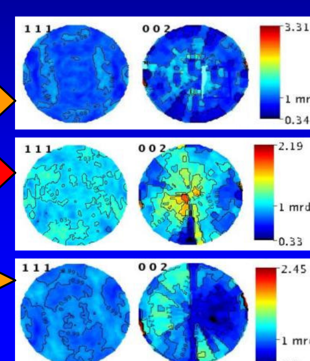
- The detection system is a MAR 345 online image plate scanner (2300 pixels, pixel size 0.15 mm).
- The one-dimensional diffraction patterns were obtained by integration of the diffraction rings of the two dimensional patterns.
- one complete pole figure of bovine bone takes 40 minutes.

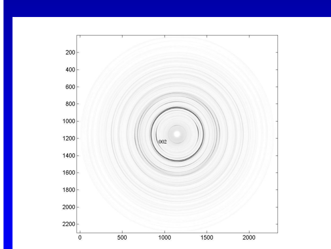
5. Results

The WIMV method has been used for describing the texture, implemented into the MAUD program (Materiel Analysis Using Diffraction) of L. Lutterotti. We refined first the crystal structure from the sum of all data and afterwards the texture of the 360 whole neutron powder diffraction patterns.

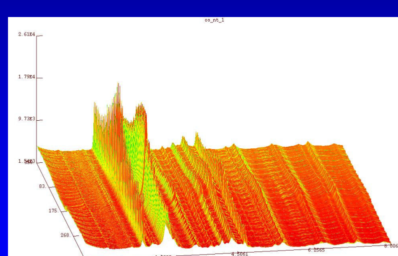








Diffraction patterns of sheep tibia, spatial resolution 350 µm, λ= 0.14Å on ID15B



684 diffraction patterns of sheep tibia.

6. Conclusion

- ID15B show that the bone has a preferred orientation in the direction of the stresses which the bones need to withstand.
- D20 has a PSD detector then it is very necessary to use the Euler cradle in order to measure the texture, on the other hand ID15B has a area detector, in consequence it is enough to rotate the bone following the Z axis and to integrate the intensity of the diffraction rings.
- the orientation of HAp crystallites at the interface with an implant depend of the coating of the face of the titanium alloy, used for the implant.

➢ If the implant is coated with HAp, the HAp crystallites preserve the preferred orientation inside the bone. If the implant is not coated, the crystallites change orientation.

➢ Surface coating can reduce significantly the rejection rate of implants, therefore the HAp coating on titanium alloy should possess a very good combination of biocompability and mechanical properties.

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