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Bone : the only smart and sustainable living material

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Abstract - 200 words maximum

The objective was to present the mechanical, morphological and physico-chemical properties of bone explaining why this living material is a smart and sustainable technological system. In fact, that bone is a living material which is able to repare itself when it breaks and the only material which provides proof of existence of human being or vertebrate for more than millions of years. Meanwhile, nature and animals are source of bioinspiration for sustainable technologies, smart human living systems should also be of interest.

Keywords: Bone, sustainable living material.

I. INTRODUCTION

Mechanical properties of cortical human bone have been investigated for more than four decades. Numerous experimental investigations on bone characterization were performed; mechanical, vibrational, acoustical testing and morphological, physico-chemical investigations. Due to the techniques, different levels of investigation were performed and subsequently quantitative parameters are concerning different level of structure of bone (organ, tissue,...). Because of the complexity of the system, few investigations have been performed on mechanical, morphological and physico-chemical properties of bone.

II. METHODOLOGY AND MATERIALS

Investigations were performed simultaneously on mechanical, morphological and physico-chemical properties of bone. In that context the influence of multiscale structural characteristics of the bone tissue on its mechanical behavior could be assessed and their estimations from micro-macro numerical modelling derived from on our experimental data [1, 2, 3]. Different methods of measurements were performed at different scales of the bone as illustrated in Figure 1. Measurements were performed on different specimen of human bone reflecting the different age evolution. Data were available from previous work in our team on rat wistar from different age and bovine, allowing multiphysical properties between species to be compared. Furthermore, a fossil bone of Masol of 2.8 Million years old has been investigated, that specimen was provided by the French Mission in India Anne Dambricourt Malassé UMR CNRS 7194 [4].

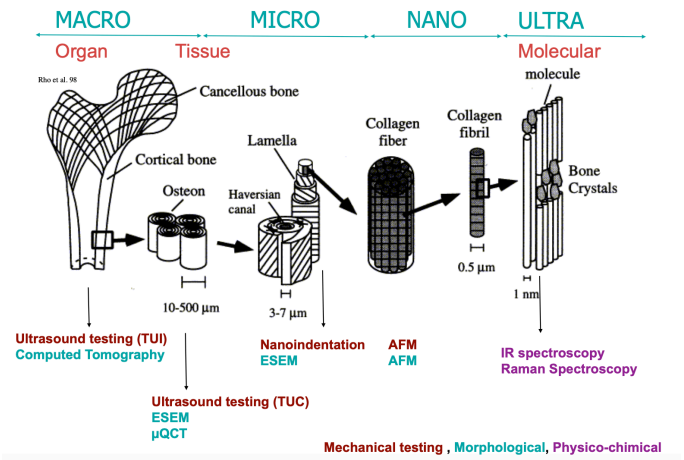

Figure 1. Identification of different techniques of measurements performed at different scales.(Figure extracted from Rho et al. 98, modified)
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III. RESULTS AND DISCUSSION

Results showed that variation of mechanical properties is correlated with morphological and physico-chemical properties with age. The 'design' of bone material at the microstructural level showed its optimisation with species, adaptation of the system for remodelling, durability, sustainability is obvious. This is illustrated by the haversian system with osteon and haversian canals (Figure 2). Understanding this mechanism is of interest for the development of similar mechanisms in order to repair, replace bone resultant from different bone disease. Values of mechanical properties at the micro and macroscopic levels are related to this design (implying the anisotropic behavior at the macrolevel).
What is remarkable is that the haversian system can still be seen on fossil bone (Figure 3). Meanwhile their mechanical properties exhibit higher values due to the sedimentation.

Figure 2 illustrates the different degree of mineralization of the osteon (osteon size about 200µm), the black holes represented haversian canals (diameters around 15µm). This heterogeneity reflects bone remodelling.

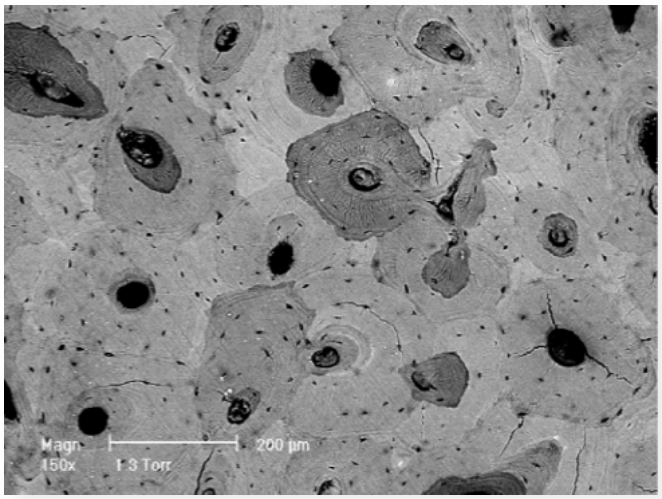

Figure 2. Haversian system of human cortical bone visualised from ESEM.
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Figure 3 illustrates the visualization of an osteon of the haversian system of the fossil bone of Masol. Despite the age, the osteon lamellae, the canal are clearly visible.

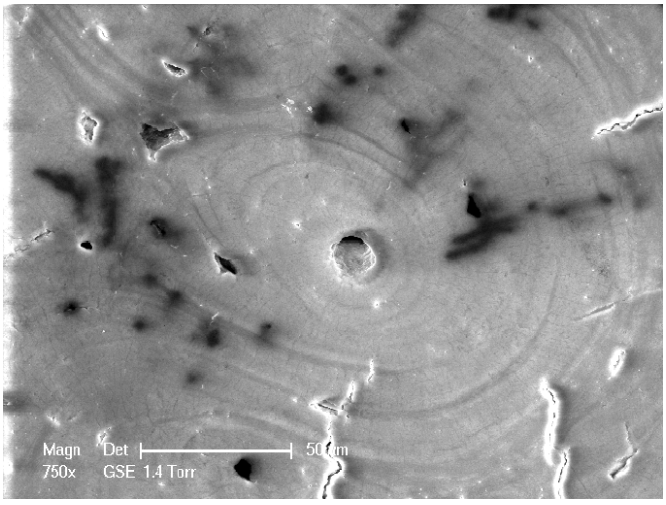

Figure 3. Osteon of the Haversian system of fossil bone of Masol 2.8 Million years old.
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