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DIGITAL IMAGE CORRELATION, NANOINDENTATION AND NUMERICAL SIMULATIONS IN THE EVALUATION OF BONE TISSUES MECHANICAL PROPERTIES

Grzegorz Kokot[1]*, Marcin Binkowski[2], Wacław Kuś[1], Przemysław Makowski[1],

[1] Silesian University of Technology, Institute of Computational Mechanics and Engineering, Konarskiego 18A, 44-100 Gliwice, Poland, gkokot@polsl.pl, wkus@polsl.pl, pmakowski@polsl.pl
[2] University of Silesia, Department of Biomedical Computer Systems, Institute of Computer Science, Będzińska 39, 41-200 Sosnowiec, Poland, marcin.binkowski@us.edu.pl

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The application of classical methods of experimental research in the evaluation of mechanical properties of bone tissues, in most cases allows to determine the material property only on the macrostructure level [1] and often is characterize by a low precision of measurement. It is also difficult to evaluate accurate stress-strain characteristics required in numerical modeling of complicated phenomena such as bone remodeling or fracture. In many cases it is connected with difficulties of the precise displacement measurements. Still new methods for more precise and accurate evaluation of bone tissues mechanical properties, with particular consideration of the hierarchical structure of the bone, are looking for.

The paper presents research results in the field of the evaluation of mechanical properties of bone tissues using new measurement techniques in experimental research, such as Digital Image Correlation (DIC), nanoindentation, and selected computational engineering methods: finite element method (FEM) and evolutionary algorithms applied to numerical identification of bone microstructural mechanical properties. Those methods are successfully applied in mechanics and application them in the biomechanics is a promising research direction [3].

The Digital Image Correlation is an optical full-field technique for non-contact, 3D deformation measurements, where the high contrast speckle pattern applied onto the surface of the sample is observed by the CCD cameras during loading (Fig 1a). Specialized software is used to analyzing the captured images during deformation and recalculation them to the form of the displacements/strains field (Fig 1b) which can be directly compare with results from the FE analysis. This is the great opportunity to direct validation of the numerical models.

In the conducted research the DIC system was combined with the classical experimental tests (tension/compression, three point bending). Such combination considerably enhances possibility in evaluating the mechanical properties of bone tissues, particularly at the macrostructure level.

In the research on the evaluation of properties on micro-and nanostructures levels works on using the nanoindentation method (Fig 1c,d), which is taken from the mechanical testing of thin metallic coatings, were carried out. The research on the evaluation of individual material properties of single trabeculae, osteons or lamelae has been conducted and achieved results are very promising. Using the nanoindentation and the Olivier-Pharr method [4] material properties (Young modulus, microhardness) at the microstructure level have been determined.

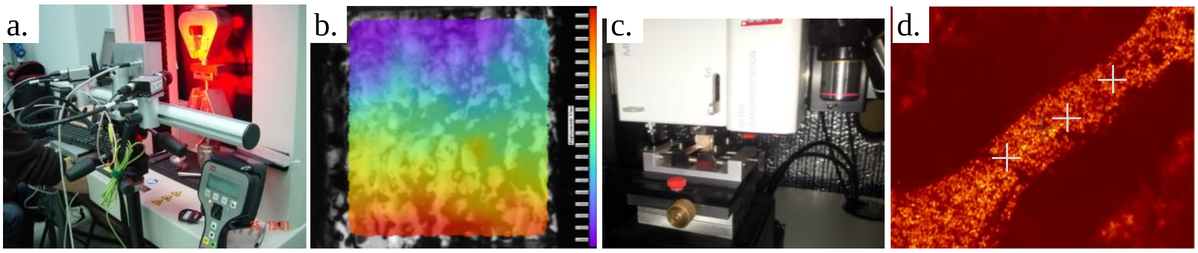

Fig. 1. a). The DIC system, b). the displacement filed on the specimen with speckle pattern, c). the nanoindentation tester, d). single trabeculae with marked points of indentation

Apart from mechanical and optical methods of evaluating the mechanical properties of bone tissues, large opportunities also provide the computational engineering methods. Especially intensively developed methods based on the FEM and evolutionary optimization methods, allow the numerical evaluation of unknown mechanical properties conducting the numerical identification of material parameters [2]. As the example of such approach the inverse problem of identification of single trabeculae material properties has been defined. In the problem definition the information from experimental tests using DIC have been used and obtained results (trabeculae Young modulus, Poisson ratio) were successfully verified by the nanoindentation test. The human bone specimen and built on the base of the μQCT scans discrete FEM model is presented on the Fig 2.

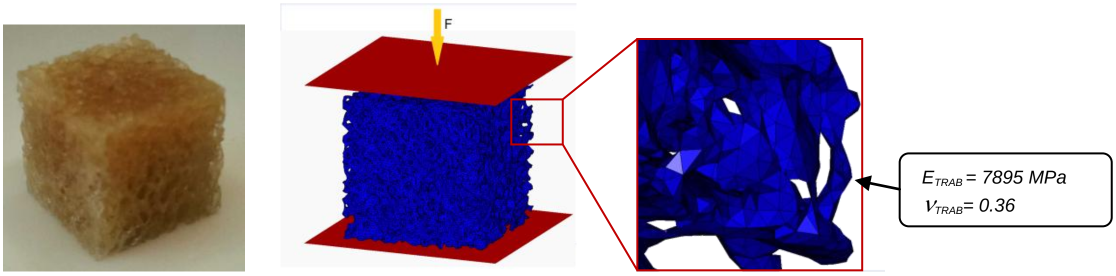

Fig. 2. The bone specimen and the FEM model with trabeculae parameters determined on the base of the evolutionary identification process

The presented methods and research results can be helpful in solving the complex biomechanics problems. They extend the possibility of numerical simulations of biomechanics structures and the evaluation of mechanical properties of the bone tissues on different structure levels.

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