Euromech Colloquium 579 – **Generalized and microstructured continua: new ideas in modeling and applications to structures with (nearly-)inextensible fibers**
April 3–8, 2017, Arpino, Italy

MULTIPHASE MODELLING OF ARTICULAR CARTILAGE AS CONTINUA WITH QUASI-INEXTENSIBLE FIBERS BY A PURELY VARIATIONAL MACROSCOPIC THEORY OF POROELASTICITY

Roberto Serpieri[1], Francesco Travascio[2]

[1] Dipartimento di Ingegneria, Universit degli Studi del Sannio,
Piazza Roma, 21 - I. 82100, Benevento, Italy. e-mail: roberto.serpieri@unisannio.it

[2] Biomechanics Research Laboratory, Dept. of Industrial Engineering, University of Miami,
1251 Memorial Drive, MEB 276, Coral Gables, FL, 33146, USA. e-mail: f.travascio@miami.edu

Key words: *Cartilage, VMTPM, Coupled Problems, Multiphysics Problems, Applications, Computing Methods.*

Cartilaginous tissues in the human body are structurally classified as soft hydrated tissues. Their peculiar structure is characterized by solid matrix, accounting for 15 to 20% of the total volume, embedded into a fluid phase. Major structural components of the solid matrix are collagen fibers which, due to their composition and the physiological mechanical loading conditions they undergo, can be considered nearly-inextensible fibers [1]. Therefore, such tissues are generally regarded as porous media with fibrous microstructure.

Macroscopic modelling of the response to mechanical loading of cartilaginous tissues, such as articular cartilage, meniscus and intervertebral disc, is commonly approached in the framework of continuum mechanics [2, 3, 4]. The multiphase, porous and microstructured nature of these mechanical systems finds a natural class of continuum models in theories of multiphase poroelastic media described as superposed continua with microstructure [5, 6, 7], providing also a basis for discrete FE models.

This class of multiphase mechanical models requires a consistent treatment of boundary conditions determining how stresses originated by joint loads are partitioned among the constituent solid and fluid phase. The question may thus be raised on whether boundary conditions and momentum balance equations of the multiphase system are affected by the fibrous nature of the micro-structure of cartilage and by its anisotropic features. In relation to this question, general momentum balance equations and boundary conditions, of both stress-type and displacement-type, have been recently derived in [8] in the context of a general Variational Macroscopic continuum Theory of two-phase saturated Porous Media (VMTPM), proceeding from the consideration of a minimal set of kinematic descriptors. Specifically, VMTPM predicts that external stresses must be partitioned according to a

medium-independent relation which, from a merely formal point of view, coincides with Terzaghi's partitioning law for soils in Geomechanics. In the context of this theory, it is found that momentum balances and boundary conditions are medium-independent, i.e., that these equations, which imply stress partitioning á la Terzaghi, must hold irrespective of the constitutive and microstructural features of the considered medium as well as irrespective of its degree of anisotropy. These results are presented and their validity is discussed in relation to modeling of cartilage as a continuous two-phase medium with microstructure composed by inextensible or nearly-inextensible fibers.

REFERENCES

[1] A.J. Sophia Fox, A. Bedi, S.A. Rodeo. The basic science of articular cartilage: structure, composition, and function. *Sports health*, Vol. **1**(6), 461–468, 2009.

[2] V.C. Mow, S.C. Kuei, W.M. Lai, C.G. Armstrong. Biphasic creep and stress relaxation of articular cartilage in compression: theory and experiments. *Journ. Biomech. Eng.*, Vol. **102**(1), 73–84, 1980.

[3] W. Ehlers, N. Karajan, B. Markert. An extended biphasic model for charged hydrated tissues with application to the intervertebral disc. *Biomechanics and modeling in mechanobiology*, **8**(3), 233–251, 2009.

[4] M. Qasim, R.N. Natarajan, H.S. An, G.B. Andersson. Initiation and progression of mechanical damage in the intervertebral disc under cyclic loading using continuum damage mechanics methodology: a finite element study. *Journal of biomechanics*, **45**(11), 1934–1940, 2012.

[5] V.C. Mow, M.H. Holmes, W.M. Lai. Fluid transport and mechanical properties of articular cartilage: a review. *Journal of biomechanics*, **17**(5), 377–394, 1984.

[6] A. Tomic, A. Grillo, S. Federico. Poroelastic materials reinforced by statistically oriented fibresnumerical implementation and application to articular cartilage. IMA Journal of Applied Mathematics, hxu039, 2014.

[7] C.Y. Huang, F. Travascio, W.Y. Gu. Quantitative analysis of exogenous IGF-1 administration of intervertebral disc through intradiscal injection. *Journal of biomechanics*, 45(7), 1149–1155, 2012.

[8] R. Serpieri, F. Travascio. *Variational Macroscopic Two-Phase Poroelasticity*, Series: Advanced Structured Materials, **67**, Springer, 2017.