MECHANICS OF SATURATED HIGH POROSITY/SOFT MATERIALS

Józef Kubik, Mariusz Kaczmarek, Michał Pakuła

Bydgoszcz University, Inst. Env. Mech. Appl. Comp. Sci, Chodkiewicza30, 85-064 Bydgoszcz, Poland

Summary Dynamical properties and macroscopic modelling of fluid saturated high porosity and/or soft materials are considered. The properties are obtained form ultrasonic tests and discussed in light of results for low and medium porosity materials. The effective medium approximations are applied in order to evaluate elasticity parameters and microscopic considerations with averaging to find interaction forces of the two-phase model. Results for wave propagation parameters as functions of porosity, frequency and parameters of structure of solid skeleton which contribute to dissipation are analysed and compared with available data.

INTRODUCTION

There is a quite large number of natural (biological) or artificial (absorbing) porous materials with high porosity. Porosity of trabecular bones, particularly in diseased – osteoporotic state may reach 95%. Soft porous materials such as foams, gels or structured liquids (e. g. magnetic liquids) may have even higher porosity and additionally very low stiffness of their solid frame. The high porosity and/or low stiffness result in specific properties of the materials as compared with materials having low or average porosity. The particular role may be played then by transfer of loads or energy in fluid, viscous dissipation in fluid due to its deformation rate (term usually neglected in modelling of lower porosity materials), interactions between phases represented by couplings in stress tensors and drag or dynamic couplings, as well as the history dependence of the interactions. In experimental studies of waves in such materials one observes for example extremely high dispersion of fast longitudinal wave and attenuation of fast wave higher than that for slow wave in some range of frequencies. Another specific property of the materials comprises in presence of maximum of attenuation for certain range of high porosities. While the theoretical studies of porous materials belong to strongly developing field of mechanics, relatively little attention is devoted to modelling of high porosity materials. As the result the knowledge of specific constitutive functions, boundary conditions, and material parameters as well as the usefulness of predictions of the classical porous media model (for lower porosity materials) are not well established.

The purpose of this paper is to consider predictions and applicability of the macroscopic model of porous media for high porosity materials. Experimental results for trabecular bones are used to illustrate the peculiarities of the materials and few theoretical aspects of the macroscopic modelling such as problems of effective elasticity parameters, role of viscous dissipation in fluid and solid materials, history dependence of interaction force and their meaning for wave characteristics are considered.

DATA FROM STUDIES OF HIGH POROSITY TRABECULAR BONES

Experiments for bovine trabecular bones saturated with marrow, alcohol and water have been performed by using pulse transmission method and the immersion technique. Three unfocused pairs of broadband ultrasonic transducers (Panametrics 2.25, 1.00 and 0.50 MHz) were applied with the ultrasonic pulser-receiver (Panametrics 5058). The received signals have been digitized by oscilloscope (TDS420A) and transferred to PC. The phase velocity and attenuation coefficient were obtained as functions of frequency based on FFT of signals transmitted through samples of different thickness. Figure 1 shows time records for waves transmitted in the same sample of water saturated bone at different frequencies of transducers.

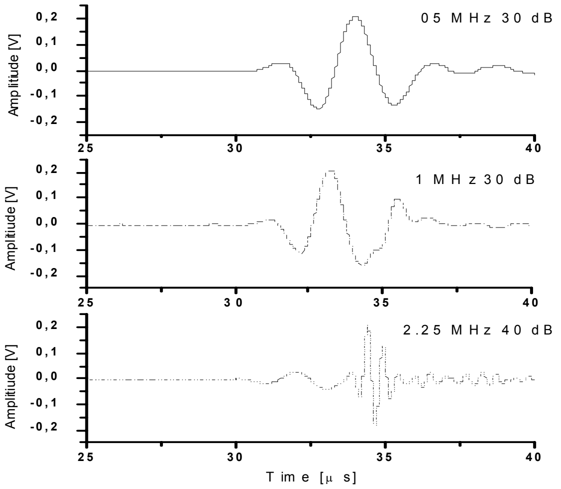

Fig.1

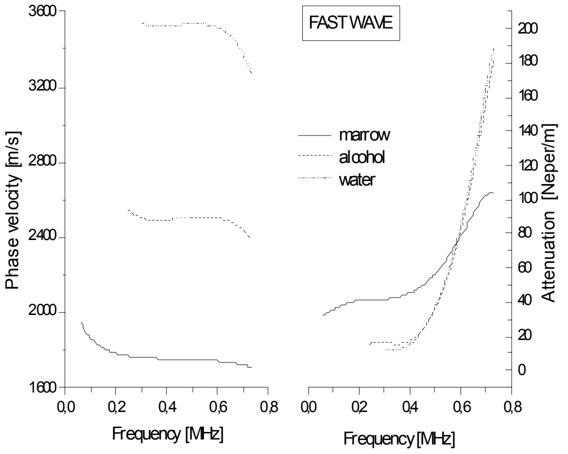

Fig. 2

Strong frequency dependence of the waves is visible. For the highest frequency (2.25 MHz) separated longitudinal wave modes can be identified and the amplitude of the fast wave becomes significantly smaller than that for the slow one. Such behaviour is not observed for other types of liquid saturated porous materials and does not agree with results known from the Biot's theory applied for lower porosity materials. In Fig. 2 the frequency dependence of phase velocity and attenuation of the fast wave measured with transducers 0.5 MHz for materials saturated with marrow, alcohol and water are compared. The results show significant negative dispersion, and strong frequency dependence of attenuation.

MACROSCOPIC MODELLING OF HIGH POROSITY MATERIALS

The macroscopic approach which can be applied as a starting point to model dynamical behaviour of saturated high porosity materials is the Biot's theory [1, 2]. The model takes into account mechanical interaction of phases due to their equipresence in elementary volumes (macroscopic particle) and interaction being result of relative motion of phases. The elastic characteristics of isotropic material within the Biot's theory define four constants. Besides the experimental techniques which for the high porosity materials were not well developed a way to determine elasticity constants is to use theoretical relations between elastic properties of materials of phases and porosity, derived by so called effective medium approximations. The methods were mostly elaborated for low or medium porosity materials and some are not useful above certain critical value of porosity. It is also worth noticing that the effective medium theories can be applied for determination of moduli of porous materials for drained or undrained conditions. The predictions to be consistent should satisfy Gassmann relation. Within the performed studies number of effective medium models were applied to evaluate macroscopic elastic parameters of high porosity materials. In Fig. 3 and 4 results for bulk drained moduli and shear moduli refered to the corresponding parameters of solid materials are compared using Differential Medium (DM), Gauss Open Cell (OC) and Two Cut (TC) models as well as giving identical results Mori-Tanaka and Kuster-Toksoz model (MT/KT). One should notice that the two Gaussian models were established [3] particularly for high porosity materials by computer simulation methods.

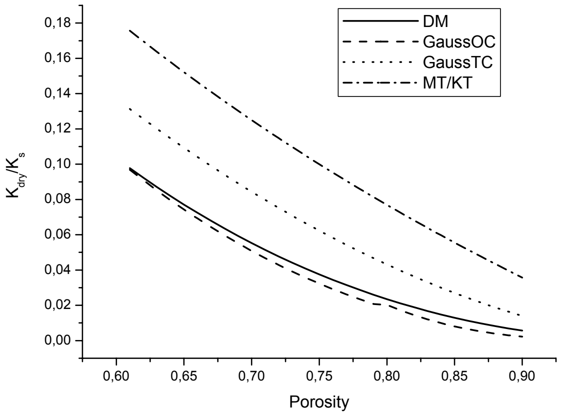

Fig. 3

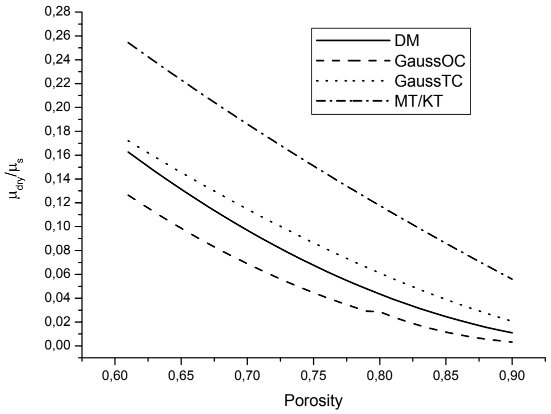

Fig. 4

The macroscopic elasticity constants derived from effective medium models were used to determine wave parameters as functions of porosity and good approximation of experimentally observed wave velocities could be obtained. The studies have also shown that due to the low stiffness of the skeleton the results for fast longitudinal wave derived with help of bulk moduli of high porosity materials are close to the results obtained for suspension model of the materials. Analysis for attenuation shows much more sensitivity of the parameter to micro-geometry (structural parameters) and the fact that the solid component constitutes continuous phase has a crucial meaning.

References

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