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Ultrasonic characterization of water saturated double porosity media

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Abstract

Wave propagation through a multilayered structure consisting of a water saturated double porosity medium in an aluminum rectangular box immersed in water is studied. By assuming a plane incident wave from water onto the structure, the reflection and transmission coefficients are derived by application of the boundary conditions at each interface. Numerical computations are done for two particular double porosity media, ROBU® and Tobermorite 11 Å, that are assumed to obey Berryman's extension of Biot's theory [Berryman 1995, 2000]. The influence of the thickness of double porosity medium is investigated. To compare experiments to computations, two comparison coefficients C_{num} and C_{exp} are introduced. The theoretical one C_{num} is defined as the ratio of the transmission coefficient of the structure to the transmission coefficient of the box filled exclusively with water. The experimental comparison coefficient C_{exp} is defined as the ratio of the Fourier transforms of the transmitted signals by the box filled with the double porous medium to that of the transmitted signals by the box filled with water. A method of minimization based on a gradient descent algorithm is used to optimize some of the parameters of the double porosity media such as the bulk moduli.

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Keywords: Double porosity media ; Ultrasonic transmission

1. Introduction

The problems of wave propagation in fluid-saturated double porosity media are subjects of growing interest in the field of geophysics (Berryman and Wang (1995, 2000), Dai *et al.* (2006, 2008), Lyu *et al.* (2014)). Based on Biot's theory Biot (1956), Berryman and Wang (1995, 2000), proposed a phenomenological model that describes the

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acoustic wave propagation through a fluid-saturated double porosity medium. Later, using the Berryman and Wang theory, Dai and Kuang (2006, 2008), calculated the reflection and transmission coefficients at the interface between semi-infinite dual porosity solids and porous, elastic or liquid media and then determined the mode conversion of poro-elastic waves. In the present study one focuses on a technique of ultrasound wave transmission through a multilayered structure consisting of a sample of water saturated double porosity medium in a rectangular box immersed in water. Numerical computations are done for two particular double porosity media, ROBU® (the individual grains are compacted microscopic beads of borosilicate glass 3.3) and Tobermorite 11 Å (the individual porous cement grains have irregular shapes).

2. Materials and experimental set up

Fig. 1 shows the images of a grain of each material obtained in Scanning Electron Microscopy (SEM). Before measurement, the materials were washed with demineralized water several times to remove the powder. The physicals properties of the materials with dual porosity are given in Table1.

Table 1. Properties of the double porosity media under study. The parameters defined in Berryman *et al.* (1995).

Parameter	ROBU®	Tobermorite 11 Å
ρ_s (kg/m^3)	2230	2100
K_s (GPa)	4.55	1.5
$K_s^{(1)}$ (GPa)	3	0.9
β	0.538	0.70
β_1	0.30	0.50
β_2	1.0	1.0
$k^{(11)}$ (m^2)	2.9x10^{-11}	2x10^{-13}
$k^{(22)}$ (m^2)	2.5x10^{-9}	2x10^{-9}
$v^{(1)}$	0.66	0.60
$v^{(2)}$	0.34	0.40
K_u (GPa)	2.45	1.5
K_1 (GPa)	1	0.05
K_2 (GPa)	0.032	0.089
K (GPa)	0.09	0.08
μ (GPa)	0.08	0.07

Fig. 1. Photos of grains : (a) ROBU at 20x and (b) Tobermorite 11 Å at 18x

A square aluminium box of internal dimensions in cm Length x Width x Height 10X10X45 is placed in a large enough water filled tank, in order to avoid echoes from the walls during the measurements. Wall thickness of the aluminium box is equal to 0.2 cm. The box may be completed either by water or by a double porosity medium saturated by water. The measurements are performed at a temperature of 18° C. Two ultrasonic transducers of central frequency 100 kHz, the one acting as a transmitter and the second one as a receiver, are applied on opposite sides of the box ; thus the configuration studied in the present paper is that of the normal incidence.

3. Theory

A numerical simulation is conducted by considering a model plane harmonic and homogenous wave of angular frequency ω. The incident wave propagates from the water normally to the faces of the box. It crosses both the aluminum and the porous medium and gives rise on one side of the box to reflected waves and on the opposite side to transmitted waves. The reflection (R) and transmission (T) coefficients are calculated from the application of the