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A new way to construct synthetic porous fractured medium

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ABSTRACT

We have developed a new, efficient and feasible methodology of fractured sample construction, based on: cement, sand, styrofoam and paint thinner. The styrofoam cuts (square pieces or penny-shaped cuts) are chemically leached out using solvent. The empty spaces created by this leaching process can represent fractures or cracks in a porous background. Usually, the sample matrix's petrophysical parameters are a function of pressure, temperature and/or cement content. In this work, all the samples were constructed under the same pressure and temperature conditions, as well as the same cement content, varying only the fracture or crack density. To demonstrate the feasibility of our methodology, we showed that is it possible to obtain accurate and reliable *P*- and *S*-wave ultrasonic velocities measurements and the Thomsen parameters (ε and γ) related to them, even if the sample presents a high fracture density, due to the high quality of the acquired waveform, expressed in a high signal-to-noise ratio. Moreover, we observed an intrinsic anisotropy in the matrix induced by the layering presented in our construction methodology. This feature, along with the presence of different fault planes orientations induced by the styrofoam holders, opens the possibility to construct samples with more complex anisotropic behavior, such as orthorhombic or monoclinic samples. Finally, this new methodology highlights the possibility of using less expensive materials to construct anisotropic media in a low-time consuming manner. These measurements were performed in two fractured samples and in a reference sample, which exhibited a small intrinsic anisotropy.

1. Introduction

The attempt to reproduce the Earth's geological properties in laboratory makes the experimental Geophysicists that work with physical modeling an “artisan” of rocks. Synthetic anisotropic media can be crafted by different methods. Using precise and sophisticated equipment, artificial fractures and/or cracks can be created in an anisotropic/isotropic background using the laser-etched (Stewart et al., 2013) and 3D printer (Huang et al., 2016) techniques. These techniques allow the creation any type of anisotropic medium with different types of physical fracture properties (aspect ratio, cracking density, etc) to be created with an unmatched precision. These techniques are a stepping-stone in seismic physical modeling. However, all this precision and robustness require high technologies unavailable in most of academics centers.

With this in mind, many authors have developed different methodologies to reproduce rocks in reduced scale by using conventional, accessible and low-cost material and methods. Assad et al. (1993, 1996) created synthetic anisotropic samples composed by epoxy resin with penny-shaped rubber inclusions to study the validity of Hudson (1981) model theory. De Figueiredo et al. (2012, 2013) and Santos et al. (2015) used the same epoxy-based methods to create anisotropic samples, which were used to estimate fracture orientation by shear-wave splitting. These epoxy-made samples are very useful to investigate the effect of different crack characteristics in elastic wave propagation. However, these samples have some limitations regarding the emulation of primary porosity and permeability, for the epoxy, used as the sole material in the matrix composition, is not permeable. In order to overcome the limitations of the technique developed by Assad et al. (1993), Rathore et al. (1995) produced synthetic porous sandstones made by sand and epoxy resin. Furthermore, they developed a way to simulate penny-shape cracks by creating voids from aluminum discs introduced in the samples that were chemically dissolved and leached afterwards. This procedure made possible introducing different types of fluids inside the cracks. Later, Tillotson et al. (2011, 2012), Amalokwu et al. (2014) and Ding et al. (2014) improved the Rathore et al. (1995)'s methodology. They developed a way to produce synthetic sandstones without the use of resin as grain binder of synthetic rock samples. Their improved samples are a result of the mixture of sand, kaolinite and sodium silicate that solidifies

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into rigid rock when submitted to high temperatures.

The chemical leaching of aluminum discs by acid is a reliable method to make penny-shaped voids (Rathore et al., 1995; Tillotson et al., 2011, 2012; Amalokwu et al., 2014). Also, the construction methods of silica-cemented sandstones described above are well-accepted techniques to create synthetic proxies for real rocks. However, these methods present some disadvantages that can be improved. As a matter of fact, the construction method found in Tillotson et al. (2011, 2012) cannot be used to simulate carbonates synthetic samples, as carbonates are soluble in acid. In Ding et al. (2014)'s procedure, the samples remained in a constant temperature oven for several days, which makes the process very time-consuming. In our approach, we propose a new and efficient construction methodology of porous fractured samples, using a mixture of cement and sand. Our methodology uses styrofoam as crack/fractures holders which are, later on, chemically leached out by paint thinner. To test the feasibility of our methodology, we measured *P*- and *S*-wave ultrasonic waveforms and used them to estimate the *P*- and *S*-waves velocities and Thomsen anisotropy parameters (ε and γ) varying the fracture density of each sample. We think that the main application of this methodology, even though not done here, relies on the verification and validation of many effective medium theories (Hudson, 1981; Eshelby, 1957; Cheng, 1993; Kachanov et al., 1994 Hudson et al., 2011; etc) related to the anisotropic medium. Besides, this can be another tool to help on interpreting the seismic data related to fractured/cracked medium (Omoboya et al., 2015). It is important to mention that anisotropic samples produced by our methodology can be used to extended the flooding experiments (injection and depletion process) performed by Bhuiyan et al. (2013) in synthetic sandstones during geomechanical tests (Holt and Stenebraten, 2013) to anisotropic medium, and can also be used to investigate the effect of imbibition/drainage cycles by water/oil/gas in fluid substitution theories (Barrière et al., 2012).

2. Fractured and cracked sample preparation methodology

The construction of the synthetic rock samples as well as the ultrasonic measurements (depicted below) were performed at the Dr. Om Prakash Verma Laboratory of Petrophysics and Rock Physics (LPRP) at the Federal University of Pará, Brazil. The following methodology description corresponds to the production of fractured or cracked synthetic sandstones.

The first step to create synthetic fractured and cracked media in a porous matrix is to cut thin square films and penny-shaped discs from styrofoam pieces. Firstly, a thin slice of styrofoam with the desired width is created using a hot wire polystyrene cutter composed by electrical resistance based on nickel material (see Fig. 1a). The styrofoam squared holders (Fig. 1b) are easily and quickly made from the thin slice using a utility knife and will be used to construct the fractured samples. The styrofoam discs can be made by a hole puncher (Fig. 1c) and will be used to create the cracked samples.

After this, the rock matrix materials are chosen depending on the type of rock one wants to simulate. In this work, synthetic porous sandstone samples were generated using clean sand and cement. We sifted the clean sand to ensure a size distribution ranging from 50 to 300 μm. These components are thoroughly mixed in order to ensure homogeneity. The water is poured into the grain mixture, which starts the matrix solidification process (see Fig. 2, stage 1).

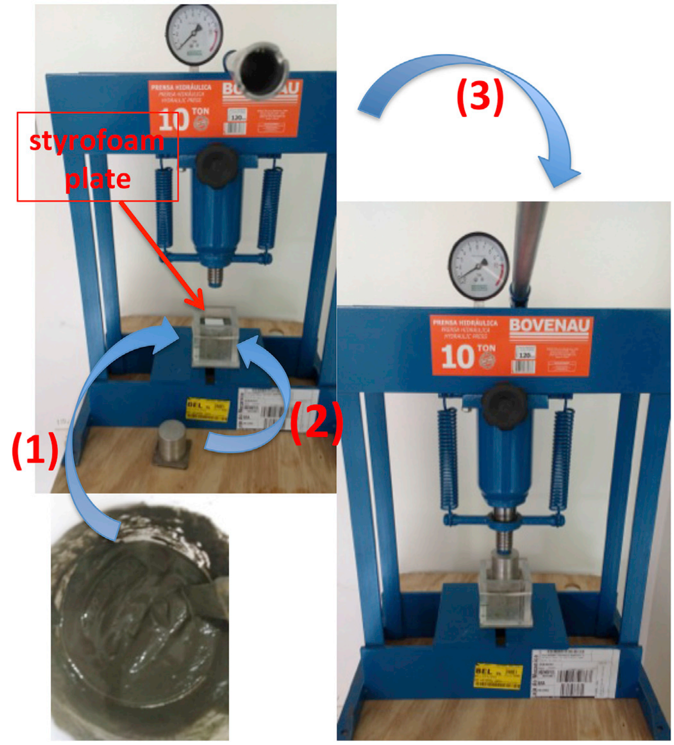

Fig. 2. Picture of the hydraulic press used to simulate de overburden effect in the synthetic rocks.

Just after the grain mixture preparation, before its complete solidification, it is poured in a mold of acrylic box (see Fig. 2, stage 1). This mold is lubricated with vaseline to facilitate the sample removal when fully solidified. In order to create planes of fracture or cracks, layers of matrix mixture and styrofoam holders are laid alternately into the mold until the desired numbers of fracture/crack planes are achieved (see Fig. 2, stage 2). During the construction of the layered sample, before laying down each one of the styrofoam holder layer, a small vertical stress is applied onto the grain mixture with the help of a steel buffer to ensure layer interface flatness (see Fig. 2, stage 3). This process of applying pressure perpendicularly to the layer interfaces causes a preferential grain orientation (due packing) in each of the layer, inducing intrinsic anisotropy in the background. The same issue is observed in Tillotson et al. (2011, 2012). The magnitude of this intrinsic anisotropy depends on the applied pressure magnitude, on the time interval between

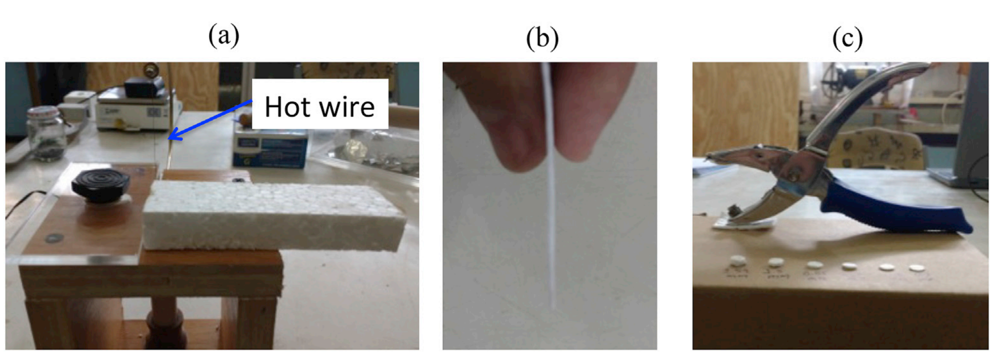

Fig. 1. a) A hot wire cutter used to produce the Styrofoam cuts; b) styrofoam squared holder and c) styrofoam disc holders in different thickness ready to use.