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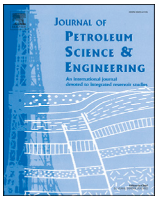

Artificial carbonate rocks: Synthesis and petrophysical characterization

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A B S T R A C T

Carbonate rocks are important for rock properties research because they are linked to significant oil and gas reserves around the world. The goal of synthesizing carbonate rocks in laboratory is to simulate the natural carbonate rock matrix regarding the main factors of lithification such as grain size and shape, concentration of cementing material and compaction pressure, and allowing the production of rock specimens that can be used for tests in extreme conditions in replacement of the high cost natural cores. The reproduction of rocks in laboratory also allows to access samples with predetermined characteristics enabling a better understanding of the relationship between their physical properties. In this work, samples of synthetic carbonate rocks were made by mixing a fixed amount of calcite and sand, and varying the amount of cement material (Portland cement and water) aiming to reproduce a primary interparticle por system. The behavior of the main petrophysical characteristics of these samples was investigated, such as porosity, permeability and P- and S-wave velocities versus the amount of cementing material. The results were compared with natural carbonate samples and showed a high similarity to the petrophysical behavior of mudstones rocks. That similarity points out the feasibility of those synthetic rocks to be used as analogous of mudstones, specifically those exhibiting only primary porosity, in experiments regarding rock physics, core flooding or rock mechanics.

1. Introduction

Carbonate rocks have a great importance to the worldwide petroleum industry, accounting approximately 50% of the world's total hydrocarbon production (Xu and Payne, 2009). These rocks cover a range of depositional facies, with considerable textural variability and complex porous media, showing a diversity of pore types, a wide range of pore sizes, and heterogeneity, which hamper the correlative analysis of its physical properties, such as porosity, permeability, elastic velocities and mineralogical composition.

Core samples of natural rocks are required for several types of tests in petroleum engineering research as core flooding performance evaluation for Enhanced Oil Recovery (EOR) techniques and formation damage investigations (Torsater et al., 2013; Sacramento et al., 2015) that may change their original characteristics, geomechanical essays (Chatterjee and Mukhopadhyay, 2002) that can be destructive and testing new methodologies for reservoir characterization (Chatterjee et al., 2012). As coring operations have a high cost, the synthesis of artificial carbonate rocks in lab environment allows the access to rock samples with analog predetermined characteristics to natural rocks, but with a relatively lower cost. Additionally, it is difficult to obtain representative carbonate samples and quantify their pore structures due to the complex pore system and high heterogeneity.

On the order hand, manufacturing physical models with known porous system allows researchers to simulate natural limestone matrix regarding the main factors of lithification as grain size and shape, the concentration of cementing materials and compression pressure. Those issues can provide the basis for quantitatively studying the pore structure effects on acoustic and petrophysical properties at ultrasonic scale (Anselmetti and Eberli, 1993; Anselmetti et al., 1998; Eberli et al., 2003; Verwer et al., 2008; Rasolofosaon et al., 2008; Weger et al., 2009).

There are many techniques available in the literature to synthesize sandstones that explored the influence of sand grain selection, type of cement and vertical compaction pressure (Klimentos and Parker, 1988; Holt et al., 1993; Den Brok et al., 1997; David et al., 1998), but few studies dealing with synthetic limestone (Piane et al., 2015; Wang et al., 2015). Niraula (2004) used crushed limestone, Portland cement and water for producing artificial core plugs to be used in rock mechanics simulations. El Husseiny et al. (2015) used cold-pressing of different mixtures of coarse and very fine calcite grains to produce synthetic

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Table 1
Quantity and material percentages used in the synthetic rocks.

Experiment	Samples	Weight fraction (%)				Quantity (g)			
		Calcite	Sand	Cement	Water	Calcite	Sand	Cement	Water
1	AT-19	95	5	20	10	120	6	25.2	12.6
1	AT-20	95	5	30	15	120	6	37.8	18.9
1	AT-21	95	5	40	20	120	6	50.4	25.2
1	AT-22	95	5	50	30	120	6	63	37.8
1	AT-23	95	5	60	40	120	6	75.6	50.4
2	AT-25	95	5	60	40	120	6	75.6	50.4
2	AT-26	95	5	50	30	120	6	63.0	37.8
2	AT-27	95	5	40	20	120	6	50.4	25.2
3	BLOCK	95	5	60	40	1200	60	756	504

Fig. 1. Cylindrical mold with mechanical compression.

micritic carbonate analogs for CO_2 injection tests.

In this work, carbonate rocks were made using a combination of sand, calcite, Portland cement and water. Our artificial samples aimed to reproduce carbonates with primary interparticle porosity. We investigated the behavior of porosity, permeability and P- and S- waves of those rocks versus the amount of cementing material. For some of the samples, we also investigated the pore space structured through pore size distribution from Mercury Injection Porosimetry (MIP) and petrographical images. The results were compared with the reported for natural mudstones and showed analogous petrophysical characteristics.

2. Methodology

The materials used to produce the synthetic rocks were: calcite, sand, Portland cement and water. The calcite and sand content in the artificial samples were based on previous experiments with natural carbonate rocks (Lima Neto et al., 2014) that had reported a composition of approximately 95% of calcite/dolomite and 5% of quartz. The used sand was previously sieved to separate grains with average sizes of 0.3 and 0.15 mm.

To prepare the samples, the dry mass of the aggregate (calcite and sand) was pre-weighed. Afterward, the cement and water percentages were based on the aggregate weight (Table 1). The artificial samples were manufactured through three different approaches (experiments) detailed hereafter. To understand the petrophysical and acoustic behavior of the manufactured samples, the amount of cement and/or water were varied.

In all the procedures, a mixer was used to blend the mineral aggregate and cementing fluid to ensure a homogeneous cover of the surface grains by the cementing fluid. The mixture was uniformly placed into a mold and was subjected to a mechanical compression for 24 h using a hydraulic press (Fig. 1). After removing the samples from the molds, they were placed in an oven and maintained for 24 h heated to 100°C. After that, the temperature was increased 25°C per hour until it reaches 300°C. Finally, the samples are cooled down to ambient temperature and could be used for testing.

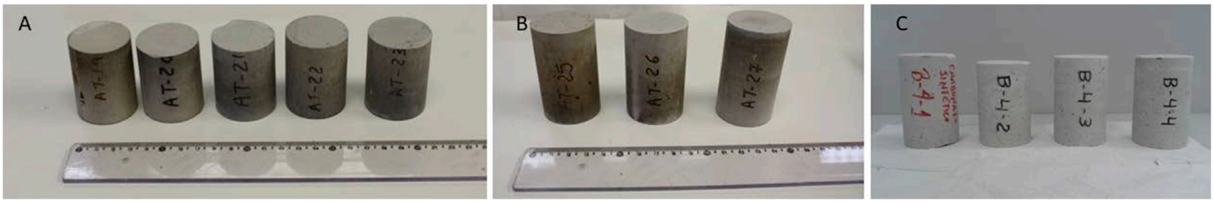

Fig. 2. Artificial samples made by experiments: 1 (A), 2 (B) and 3 (C).

Table 2
Percentage of mineral phases obtained by XRD analysis of the material used in the experimental samples.

Materials	Mineral Phase (%)						
	Silicates Phases			Carbonates Phases		Clinker compound Portland Cement	
	Quartz SiO_2	Feldspar (microcline) $KAlSi_3O_8$	Mica (biotite) $K(Mg,Fe)_3(OH,F)_2$ $(Al,Fe)Si_3O_{10}$	Calcite $CaCO_3$	Dolomite $CaMg(CO_3)_2$	Alite (Ca_3SiO_5)	Hatrurite (Ca_3SiO_5)
Sand 0.15 mm	93	1.4	5.6	0.0	0.0	0.0	0.0
Sand 0.30 mm	97.5	1.4	1.0	0.0	0.0	0.0	0.0
Calcite	4.2	0.0	0.0	76.3	13.5	0.0	0.0
Cement	4.1	0.0	0.0	35.8	3.5	43.3	13.4