[PS]Petrophysical Characterization of 3D Printed Rock and Its Substitution in the Validation Experiment*

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Abstract

Many cutting-edge technologies have the potential to become the game-changer of the oil and gas industry in the near future. 3D printing, known as rapid prototyping, is the active tool in multiple disciplines, which need to be applied further in the petroleum geology and petroleum engineering. It has been attempted to replace the natural rocks which are typically expensive and hardly accessible. However, the fundamental characteristics of 3D printed rocks have not been fully understood, and the application is in the preliminary stage.

In this study, samples from synthetic gypsum rocks, which are produced by 3D printing technology, were scanned by X-ray micro-tomography with the resolution of 8 micrometers. Petrophysical properties of pore structure, including porosity, pore size distribution, pore surface area, pore connectivity, and hydraulic radius are measured and analyzed. Using the processing software, permeability was also simulated based on the reconstructed pore model. The results from the micro-CT show that the porosity of this 3D printed rock sample is 20.84%, which is less than the result of Helium Porosimetry, 28.86%. The difference is due to the resolution effect of micro-CT that missed the micro- and nano-scale pores which are smaller than 8 micrometers. With the known petrophysical properties of 3D printed rocks, we employed these samples to substitute for the drilling rock cores in the validation experiment. The ultrasonic velocity measurements under different source frequency and confining pressure were performed in the laboratory environment. The results of the validation experiments are consistent with the theoretical prediction. This proves that 3D printed rocks can be the proper method to facilitate the efficiency of laboratory experiments.

Petrophysical Characterization of 3-D Printed Rock and Its Substitution in the Validation Experiment

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Introduction

Many cutting-edge technologies have the potential to become the game-changer of the oil and gas industry in the near future. 3D printing, known as rapid prototyping, is the active tool in multiple disciplines, which need to be applied further in the petroleum geology and petroleum engineering. It has been attempted to replace the natural rocks which are typically expensive and hardly accessible. However, the fundamental characteristics of 3D printed rocks have not been fully understood, and the application just stays in the preliminary stage. In this study, intact cylindrical samples, produced by 3D printing technology, were scanned by X-ray micro-tomography and then we estimated the petrophysical properties of pore structure, including porosity, pore size distribution, pore surface area, etc. The results from the micro-CT were compared with that of routine experimental measurement. With the known petrophysical properties of 3D printed rocks, we employed these samples to substitute for the natural rocks in the validation experiment, yielding the consistent result with the theoretical prediction, which proves that 3D printed rocks can be the proper methods to facilitate the efficiency of laboratory experiments.

Methods

The methods include the sample preparation and advanced analytical instruments.

Sample Preparation by 3D printing

CAD Design or Digital Rock → Choose material/printing system → Postprocessing

Laboratory experiments

- Micro-CT scan and analysis
- Helium Porosimetry
- Mercury Injection Porosimetry

Results

❑ 3D volume model of pore network was rendered (Fig. 1). Pore structure of 3D printed rocks, including pore size distribution, pore aspect ratio, pore sphericity and pore shape factor were measured and analyzed (Fig. 2-4). Multiple methods were employed to compare the porosity measurements (Table 1).

Table 1 The comparison of the measured porosity from HP, MIP and XCT methods.

	Helium porosimetry	Mercury injection porosimetry		Micro-CT
		$D > 0.003$ μm	$D > 8$ μm	$D > 8$ μm
Porosity	28.86%	27.90%	25.88%[a]	32.66%

D, pore diameter

[a]Calculated based on MIP pore size distribution (Fig. 3)

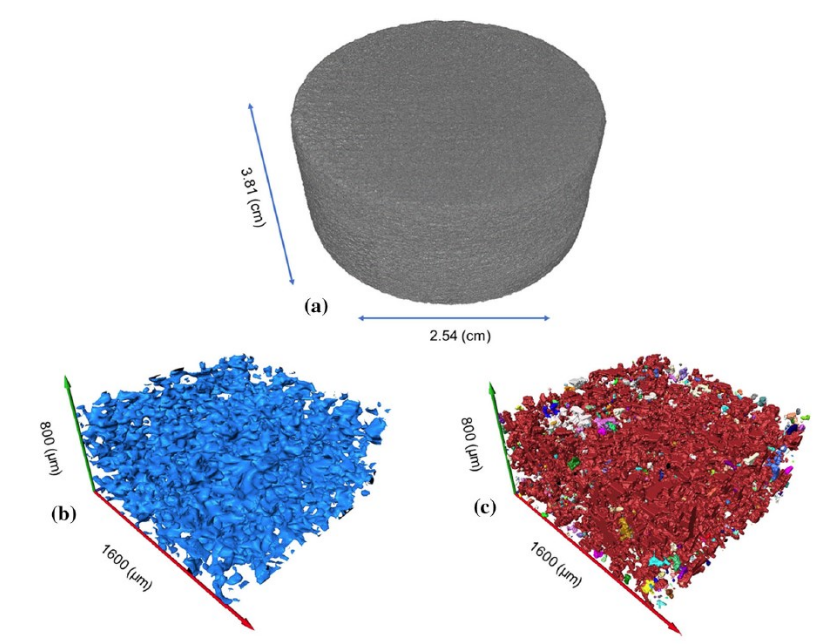


Fig. 1 (a)3D volume view of 3D printed rocks (b) Pore network (c) Separated Pores and throats

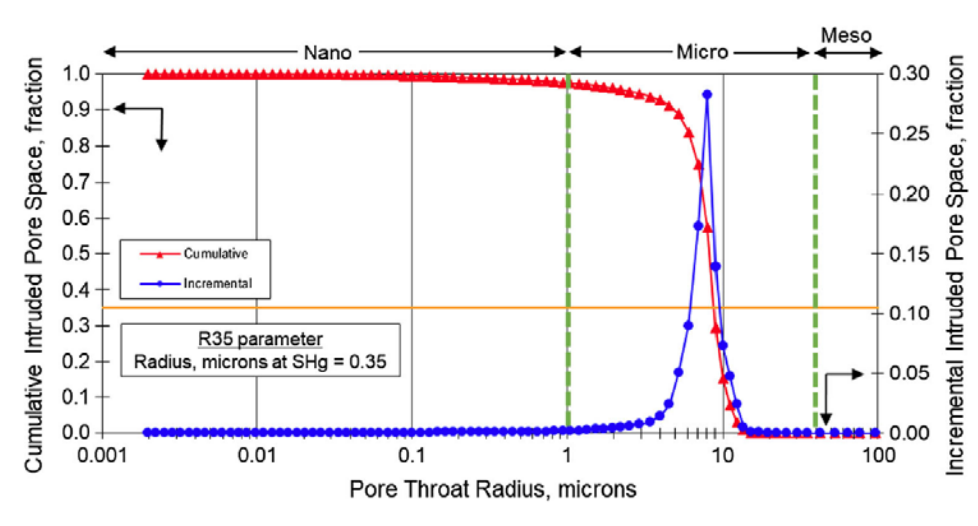


Fig. 2 Pore throat radius distribution by mercury injection porosimetry

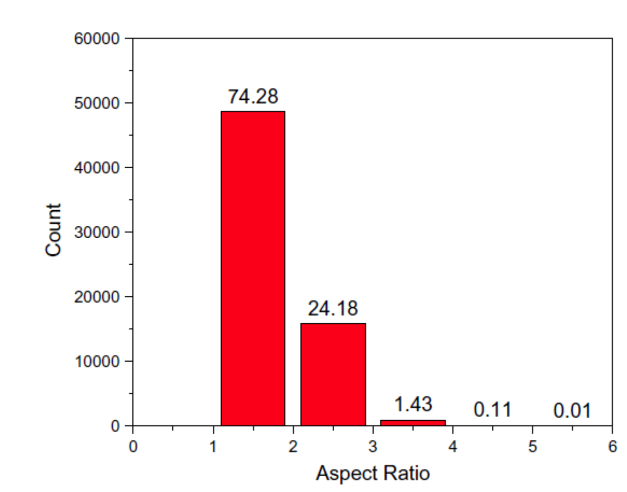


Fig. 3 Frequency histogram of aspect ratio of pore shapes.

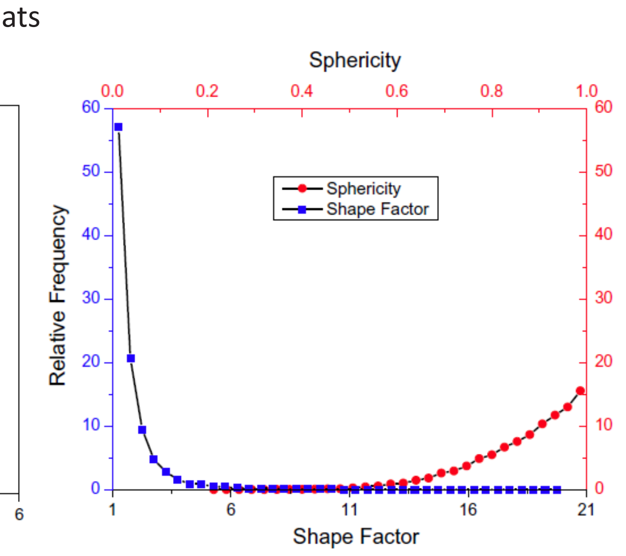
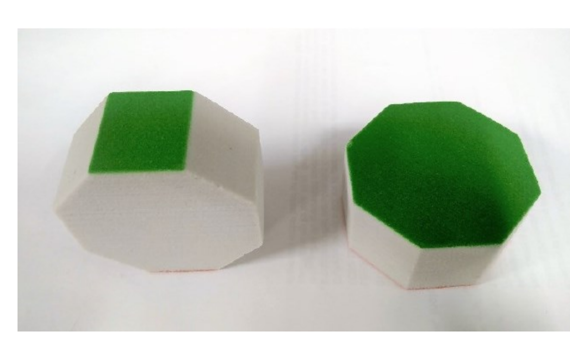
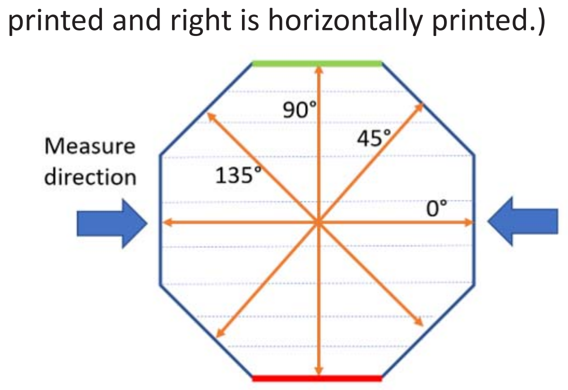


Fig. 4 Relative frequency distribution of shape factor and sphericity.

❑ 3D printed rocks were designed as octagonal prism to validate the seismic anisotropy of VTI (vertical transverse isotropy), which is cause by printing layers. The results of Vp and Vs resemble the properties of natural rocks, based on the literature.



(Printing from Red to Green. Left is vertically printed and right is horizontally printed.)



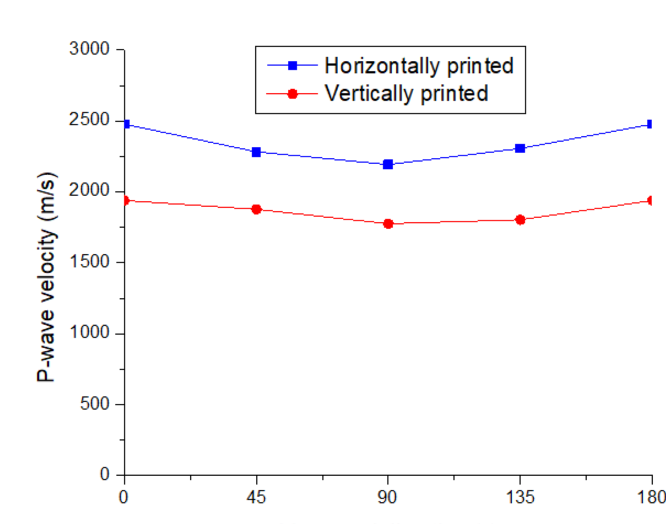


Fig. 6 P-wave velocity of horizontally and vertically printed octagonal prism at different measure direction

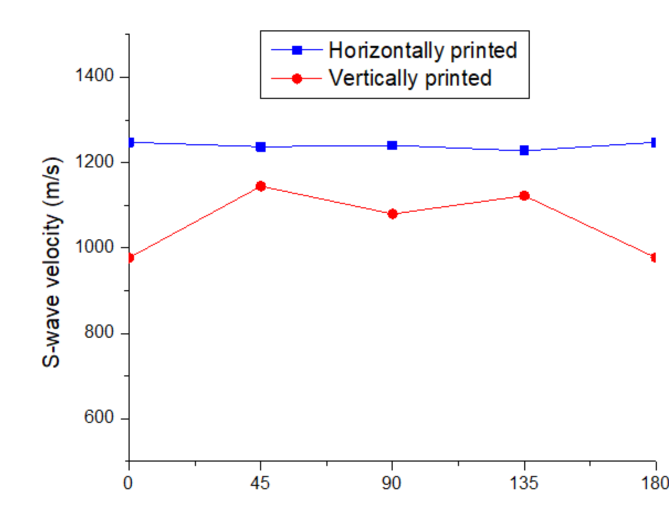


Fig. 7 S-wave velocity of horizontally and vertically printed octagonal prism at different measure direction

Conclusions

1. Micro-CT shows that the porosity of this 3D printed rock sample is 32.66 %, which is larger than the result of Helium Porosimetry, 28.86% and that of Mercury injection porosimetry, 25.88%.
2. Pore size distribution from micro-CT images showed that radius of the pores that varies from 4 to 10 um has a high frequency of 92.04% of total pore size distribution.
3. Sphericity and shape factor also indicated that 3D-printed gypsum rocks host more spherical pores and fewer blade-shaped pores.
4. 3D-printed rocks can be considered as the vertical transverse isotropy (VTI) which can be due to the printing process.
5. 3D printing technology has the potential to revolutionize the rock physics experiments, transforming the digital rock into physical model, validating the theoretical conclusion, providing porous media for upscaling, etc.

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