Construction and Experiments of Synthetic Sandstones with Controlled Fracture Parameters

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SUMMARY

We use a new method to construction synthetic sandstones containing a controlled fracture distribution and geometry. The new construction method provides synthetic rock which has similar mineral composition, cementation, porous morphology as natural rocks. We use discs of decomposable material to create fractures in rock samples. The synthetic rock samples are more realistic to natural rock, compared to any synthetic experimental samples in previous experiments about fractures. Sets of synthetic samples with controlled fracture geometry and orientation are measured with ultrasonic investigation system when saturated by air and water, and both P wave velocity and S wave velocity are measured for anisotropy analysis.
Introduction

Seismic anisotropy is a common phenomenon and we use equivalent medium theories to extract geophysics information from seismic data. Anisotropy can arise from different causes, especially aligned fractures. Knowing the fracture distribution is very important in seismic prospecting and hydrocarbon production from reservoirs. The information on fracture distribution and permeability is necessarily correlated.

We use synthetic sandstones containing aligned fractures of known distribution and geometry to analyze P- and S- wave velocity and anisotropy. The synthetic sandstones are embedded in penny shaped high molecular material discs that can be decomposed, and drained out, leaving fractures in place. We construct synthetic sandstones that are more realistic to natural rock. The P- and S- velocity of these samples are measured in ultrasonic investing system saturated by air and water.

Manufacturing synthetic sandstones

To date, there have been several experiments on fractures in synthetic rock. However, the fractured samples (e.g. Lucite, silica rubber, sand bonded by epoxy) were very different to natural rocks. We use a new construction process to create synthetic sandstones.

The materials we chose are silica sand, clay; sodium silicate is used as a binder. These materials were mixed in a ball mill to ensure homogeneous block production. Then the powder was mixed with sodium silicate, a certain amount of the mixture was laid to mould each time, and the thin high molecular material discs were spread out over the surface of each layer. Once the samples had been prepared in moulds, they were left to dry in a constant temperature oven for several days. In the final step, the blocks were sintered in a high temperature muffle furnace. The high molecular material discs were decomposed, leaving out penny shaped void fractures.

Rock physics testing

The blocks were analyzed using scanning electron microscope to observe pore structure. The SEM image is shown in Figure 1(d), with realistic pore shapes and distribution. Experiments were
performed on blank sample to determine the pressure sensitivity and layer anisotropy. The blank sample were cored to 2.54 mm diameter core, then measured in 5 MPa steps from 5 MPa – 40 MPa then 40 MPa – 5 MPa. Both P wave velocity and S wave velocity were measured at each pressure. The test results are shown in Figure 3.

Figure 3 Ultrasonic velocities versus pressure of blank sample.

(a) P-wave velocity during both loading and unloading (b) S1 and S2 wave velocity during loading

Constructing and testing the fractured sample

Figure 4 shows the fracture distribution in the sample; the discs were spread out as wide as possible over half part of each layer, the other part left blank to determine layer anisotropy. The diameters of these discs are all about 4mm, and the fracture density of the fractured part is about 0.034. Figure 4 also shows the coring process of the fractured sample. The final block was cored to four 3.8 mm cores: two blank cores (one vertical and one horizontal), two fracture cores (one cored parallel to the fractures and one perpendicular to the fractures). Figure 5 shows the 3D X-ray images of the two fractured cores.

The four cores were measured in ultrasonic investigation system saturated by air and water. Laboratory measurement results of P-wave velocity and S-wave velocity are shown in Table 1. Figure 6(a) shows the P-wave velocity of the two blank samples. The velocity in the direction perpendicular to the layering is much smaller than parallel to the layering as expected. Figure 6(b) shows the P-wave velocity of the fracture samples. The velocities of the blank and fractured samples are almost equal in the parallel direction. By comparison, the velocity of the fractured sample is much lower than the blank sample in the perpendicular direction. The S-wave velocities of the blank and fractured samples are shown in Figure 6(c) and Figure 6(d). The velocities of the fast (S1) and slow (S2) shear-waves in both directions were measured, and the amount of shear-wave splitting (SWS) in both directions of the blank and fractured samples are shown in Figure 7. Figure 8 shows the P-wave and S-wave anisotropy parameters, Thomsen parameters ε and γ, respectively, of the blank and fractured samples.

Laboratory analysis and discussion

In Figures 6(a) and 6(b), the P-wave velocity in samples saturated by water is larger than that in samples saturated by air (both for blank and fractured samples), and this effect is more obvious in the
perpendicular direction. P-wave anisotropy is very large in air-saturated samples. In contrast, for water-saturated samples, the P-wave anisotropy decreased significantly, as shown in Figure 8(a). As shown in Figures 6(c) and 6(d), the velocities of the fast (S1) shear wave in the fracture and blank samples are almost equal in the direction parallel to the fracture, whilst the velocities of the slow (S2) shear wave are comparatively lower in the fractured sample. However, in the perpendicular direction, the shear wave splitting is weak, because the difference between the S1 and S2 velocity is small. The shear wave velocity decreases when the samples were saturated by water, as compared with saturated by air. The saturation has greater influence on the S1 velocity. As shown in Figure 7, the amount of shear-wave splitting (SWS) is large in the parallel direction and small in the perpendicular direction. The shear wave anisotropy is slightly higher in the water-saturated samples than the air-saturated samples, as shown in Figure 8(b).

![Figure 5 3D X-ray CT images of two fracture cores](image)

### Table 1 P-wave and S-wave velocities

<table>
<thead>
<tr>
<th></th>
<th>Air saturated</th>
<th>Water saturated</th>
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</thead>
<tbody>
<tr>
<td>Blank samples</td>
<td>Vp(m/s)</td>
<td>Vs1(m/s)</td>
</tr>
<tr>
<td>Parallel</td>
<td>3252</td>
<td>1965</td>
</tr>
<tr>
<td>Perpendicular</td>
<td>2896</td>
<td>1839</td>
</tr>
<tr>
<td>Fracture samples</td>
<td>Vp(m/s)</td>
<td>Vs1(m/s)</td>
</tr>
<tr>
<td>Parallel</td>
<td>3254</td>
<td>1960</td>
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<tr>
<td>Perpendicular</td>
<td>2836</td>
<td>1814</td>
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</table>

The change of anisotropy is larger for the shear wave than the P-wave between the blank and fractured samples, indicating that the existence of fractures has more influence on the shear wave than the P wave. However, the decrease in P wave anisotropy is larger than the increase in shear wave anisotropy when the samples are water-saturated compared to air-saturated. This implies that the shear wave is more sensitive to the presence of fractures whilst the P-wave is more sensitive to the fluids.

**Conclusions**

Laboratory studies of fractured rock need synthetic samples with controlled fracture density and geometry. We use a new method to construct synthetic sandstones which can provide more realistic experimental samples. Experiments on fracture samples help to quantify the rock physics properties of the fractured rocks. These samples will be tested in low-frequency measurement systems for further research.

![Vp of blank sample](image)  
![Vp of fracture sample](image)

(a) P-wave velocity of the blank samples (b) P-wave velocity of the fractured samples
Figure 6 P-wave and S-wave velocities for air and water saturations

(c) S-wave velocity of the blank samples  (d) S-wave velocity of the fractured samples

Figure 7 Shear-wave splitting (SWS) in the blank and fractured samples

(a) SWS of the blank samples in both directions  (b) SWS of fracture samples in both directions

Figure 8 Anisotropy of both blank and fractured samples saturated with air and water

(a) P-wave anisotropy parameter  (b) S-wave anisotropy parameter

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References


