On the temperature dependence of elastic velocities in a synthetic porous VTI media

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Abstract

In this work we performed elastic velocities (P and S) measurements as function of temperature in a porous synthetic anisotropic sample constructed in laboratory using a new technique developed by Santos et al (2016). In order to calculate the Thomsen's parameters gamma and epsilon, measurements were made in two different directions of propagation: perpendicular and parallel to the crack planes. For temperatures ranging from 25^{o} C to 175^{o} C the P-wave velocities decreased 7.8 % and S-wave velocities 7.1 % on average. The anisotropic parameters, γ and ε remained practically constant along of this range of temperature

Introdução

Many studies have been performed on the propagation of seismic waves in vertically transversely isotropic (VTI) media along of the years. Beyond that, this type of anisotropy is the most recurrent in sedimentary settings. Being, therefore, of crucial interest to the oil industry. The importance of temperature on seismic velocities has also been verified in many studies. Timur (1977) measured acoustic velocities in two sandstone and seven carbonate samples as function of temperature. He found that the average decrease for a 100 C rise in temperature to be 1.7 percent for compressional wave velocities and 0.9 percent for shear wave velocities. Fuyong et. al (2016) investigated the temperature and pressure effects on seismic velocities of halite salt, he concluded that the temperature effect on seismic velocities of halite salt is dominantly dependent to the stress effect.

This study aims to further investigate the temperature effect on compressional and shear waves travelling in a VTI media as well as the dependence of the Thomsen's parameters (γ and ε) also, with respect to temperature. Measurements of traveltime were performed through the ultrassonic method under constant pressure as function of temperature (ranging from 25 to $175\ ^{o}C$) in a cracked sample constructed using the new technique developed by Santos et al (2017).

Metodologia

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

Sample preparation

In this anisotropic swarm, the cracks are disposed at layers that are constructed one at a time. At first, we filled the mold with a 1 cm layer of mix of sand+cement and then placed 15 penny shapped cuts of an especial material that have a 0.5 cm diameter and 0.1 cm thickness (Figure 1). Then we filled another 0.5 cm layer of cement and placed another set of penny shaped cuts as before, repeating this process until we had 8 layers with cracks spaced by 0.5 cm. Once the matrix is get rigid the sample is immersed in a liquid in an attempt to dissolve this cuts creating, that way, cracks. The sample was divided in three regions, two approximately isotropic and one anisotropic – as shown in Figure 1. The measurements were made at the anisotropic region. After prepared, the rectangular prismatic sample has a length of 20.0 cm, a width of 6.2 cm and a height of approximately 5.6 cm as shown in Figure 2.

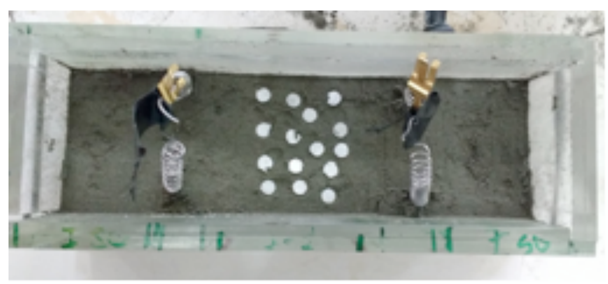

Figure 1: Cuts of an especial material used to create the anisotropic layer (Santos et al., 2017).

Temperature setup

The proposed temperature measuring system is represented in figure 3. This system is compound by: the rock sample, a power control from NOVUS model PCW-2P-150, two K-type thermocouple, a signal conditioner from Omega model TXDIN70, a DAQ device model USB-6001 from National Instruments, and a computer with the software Labview installed.

Following the diagram, starting at the measure in the

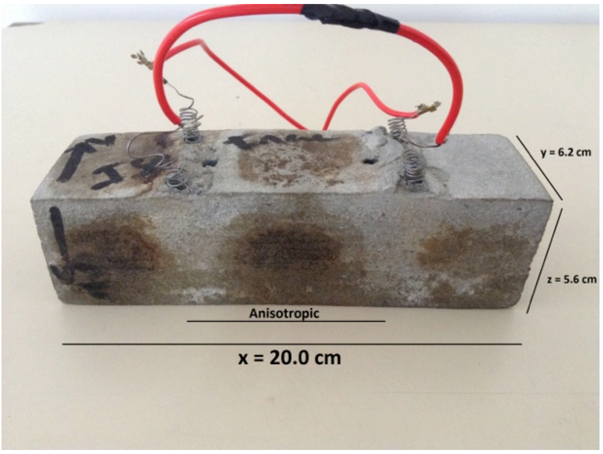

Figure 2: Top view of sample construction in the laboratory.

thermocouple, the thermocouple generates an electric potential difference in microvolt for each value of temperature measured. On the signal conditioner there is a setting mode in which the user defines which thermocouple to use. The maximum and minimum values of input and output are defined as well. For this experiment the conditioner was set to work in a linear scale for temperatures ranging from 0 to 300^{o} Celsius for currents values ranging from 0 to 20 milliamp. That way the conditioner converts voltages values from the thermocouple into currents values in milliamp and sends it to the DAQ device.

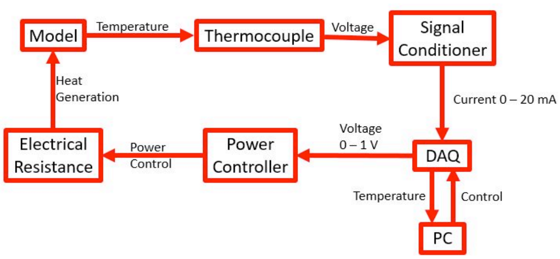

Figure 3: Temperature Control Diagram.

The DAQ device receives the current values and sends it to the computer via USB, through Labview the current is converted into temperature values and a Supervisory of the sample temperature is done using blockchain programming. On the supervisory the user defines a setpoint for the sample temperature and the DAQ, through its analogical output, sends for the power controller to provide 10 % of energy from the 220 V electrical network to heat the sample. Although this control system is ON/OFF, it can still provide good results once temperature systems are not too dynamic.

As it can be seen in Figure 2, the sample is heated by two nichrome resistances that were placed at the edges of the anisotropic region of the sample in order to heat this part evenly. The temperature measures are taken by two K-type thermocouples placed in a hole drilled in the sample near the resistances, the average value of the two thermocouples is assumed as the real temperature value.

If the temperature measured is below the value chosen by the user in the Supervisory, the DAQ sends 1 volt of tension to the power controller. The power controller is set to work with values of voltage ranging from 0 to 10 V where 0 V corresponds to 0 % of power and 10 V to 100 % of power. In order to not overshoot the desired temperatures, in this experiment the DAQ was set to send 1 V of tension whenever was needed to heat the sample.

Ultrasonic setup

The ultrasonic measurements were performed using the LPRP ultrasonic system with the pulse transmission technique of Santos et. al (2016). The sample rate by channel for all measures of S-wave form was 0.01 microsecond. Figure 4 shows the ultrasonic system. The system is compound by a pulser-receiver 5072PR and a preamplifier 5660B of Olympus, a 50 MHz USB oscilloscope of Handscoope, and two transducers of 1 MHz (P-wave) and 500 KHz (S-wave) of Olympus. Ultrasonic measurements were made in the z and y-directions as function of temperature that ranged from from 25 to $175\ ^{o}C$. Figure 5 depicts the experiment during the data acquisition.

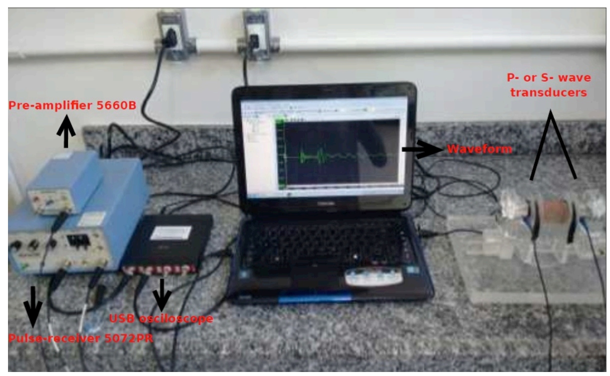

Figure 4: Ultrasonic measurement system.

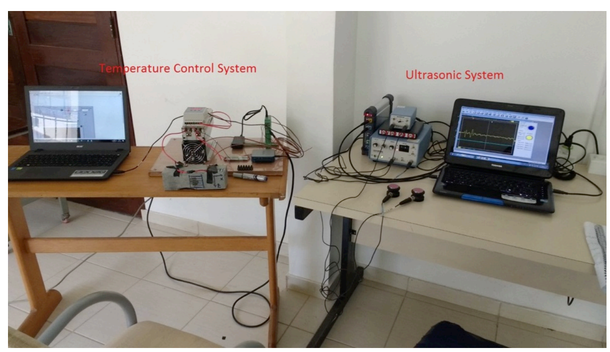

Figure 5: Temperature Control System (left) and Ultrasonic System (right).

Results

The waveforms for propagation in the Z and Y directions are shown in Figure 6 (for P and S wave modes), it can be seen that, as temperature increases, the first break time increases resulting, therefore, in a decreasing of P and S-wave velocities as well. Compressional wave velocities for propagation in the Y and Z-directions are shown in Figures 7 and 8 as function of temperature. As it was expected, velocities in the Y-direction are greater than in the Z-direction, 14% greater on average, for the symmetry axis of the media is on the Z-direction. Figure 8 shows the shear wave velocities Vs1 and Vs2 for propagation on the Y-direction, and Vsz for propagation on the Z-direction. On the average, Vs1 is 5% greater than Vs2. For the temperature range studied, the P-wave velocity change is 290 m/s (7.8 %) and the S-wave change is 170 m/s (7.1 %) on average.

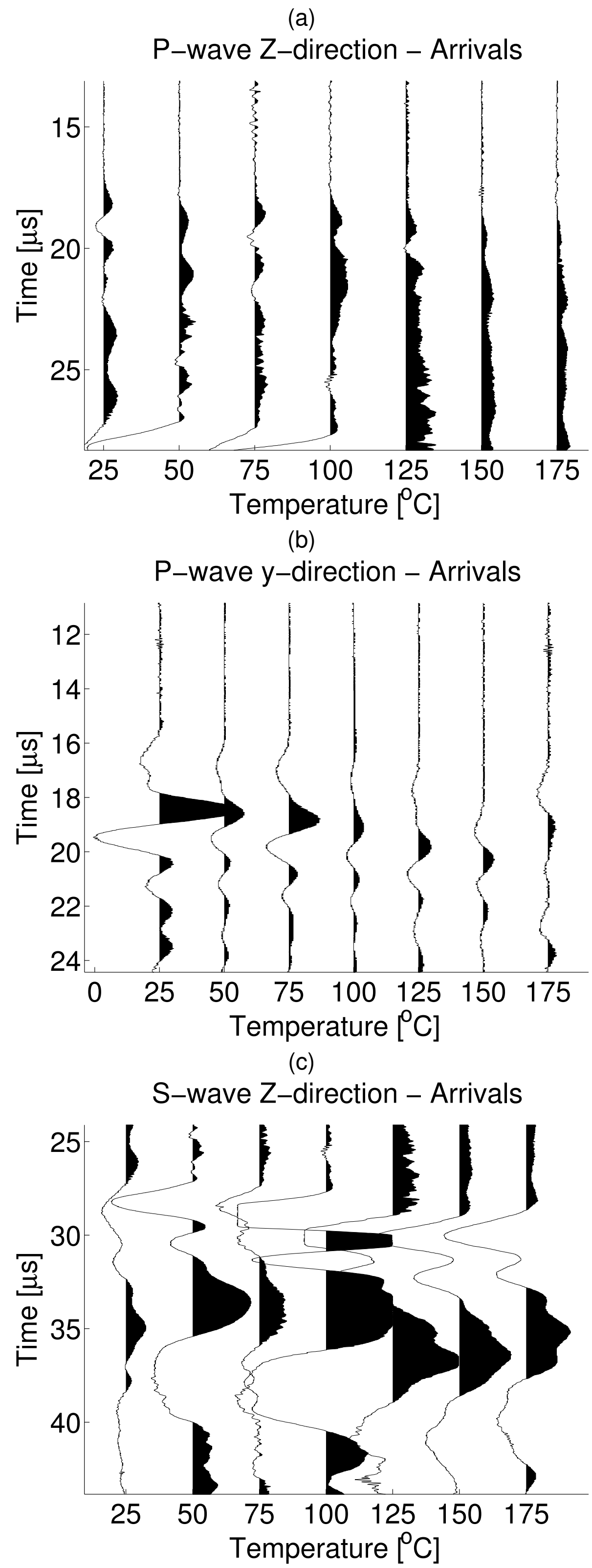

Figure 6: (a) and (b) P waveform for propagation in the Z and Y directions. c) S waveform for propagation in the Z direction.

(a)

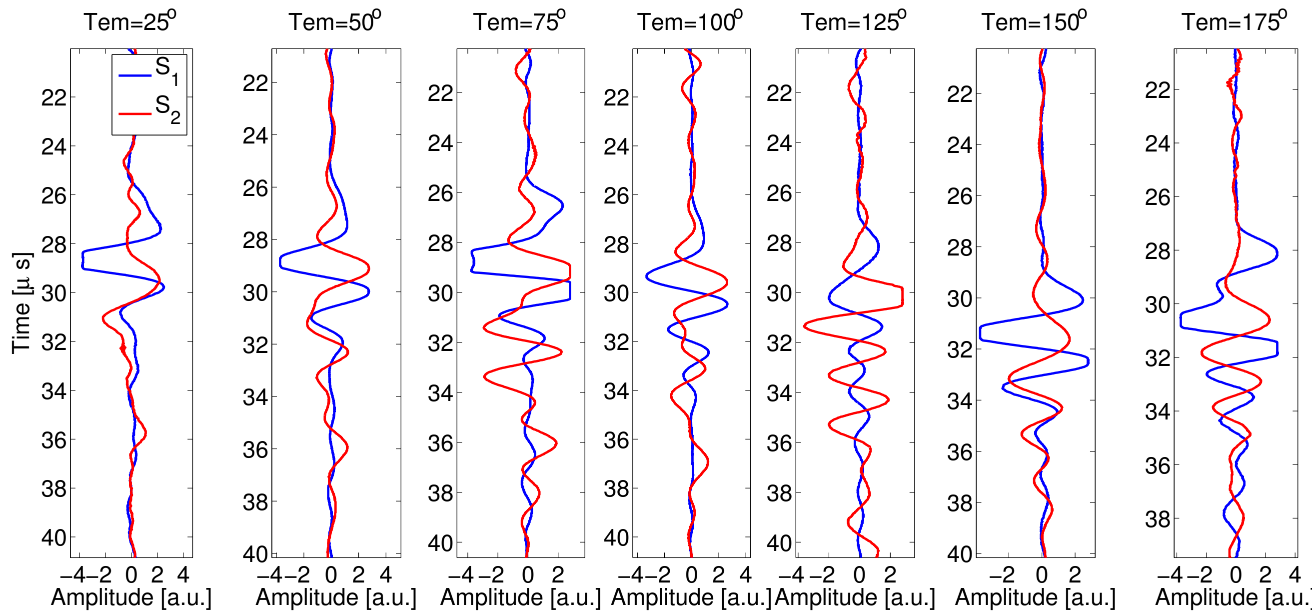

Figure 7: S waveform corresponding to propagation in Y direction. S_1 and S_2 are the two S-wave polarizations parallel and perpendicular to crack planes.

The linear equations that best fit the velocity data of Figures 7 and 8 are:

$$V_{Py} = 4011.7 - 1.98T \quad (1)$$
$$V_{Pz} = 3576.2 - 2.11T \quad (2)$$
$$V_{S1} = 2473.3 - 1.16T \quad (3)$$
$$V_{S2} = 2397.5 - 1.24T \quad (4)$$
$$V_{Sz} = 2320.3 - 1.07T \quad (5)$$

where T is the temperature in Celsus (^{o}).

These observed velocity decreases in Figures 8 and 9 may be due to the effect of temperature on the modulus of the rock sample (Aytekin, 1976). However, this effect do not fully account for the total velocity decreases once the effect of temperature on the density is in the direction of compensating these velocity decreases. Another contributing factor may be the generation of new cracks (Toksoz et al, 1976) which could have developed by thermal expansion. This latter factor might have played a major role on the observed velocity decreases since the measurements were made at constant ambient pressure.

Velocity data from Figure 8 and 9 were used to calculate the Thomsen's parameter γ and ε. The results obtained are shown in Figure 10 where it cannot be seen any correlation between the anisotropic parameters gamma and epsilon with temperature. In fact, with the exception of 25^o C gamma, the values of gamma and epsilon are approximately constant in the range of temperature studied. This might be explained by the fact that each one of these parameters depends only on either P or S-wave velocity. Therefore, even though the P-wave velocities in different directions of propagation change with temperature, they change with approximately the same gradient (equations 1 and 2) keeping ε constant.

Conclusions

Velocities of compressional and shear waves travelling in a VTI synthetic media decrease with an increasing in temperature. Compressional waves are, however, more sensitive to changes in temperature relatively to shear waves. Two possible causes for this decreasing in velocity are: the effect of temperature in the rock sample modulus and the generation of new fissures due to thermal expansion. The polarization S_2 shows to be more sensitive than S_1. This reinforces the hypothesis of creation on new cracks with the increasing of temperature

The Thomsen's parameters γ and ε do not show any apparent correlation with temperature. A future study to investigate the effect of temperature on the δ parameter. Although it can be inferred from the results that it would not remain approximately constant as γ and εa, since δ depends on both P and S-wave velocities which change at different rates with temperature.

Acknowledgments

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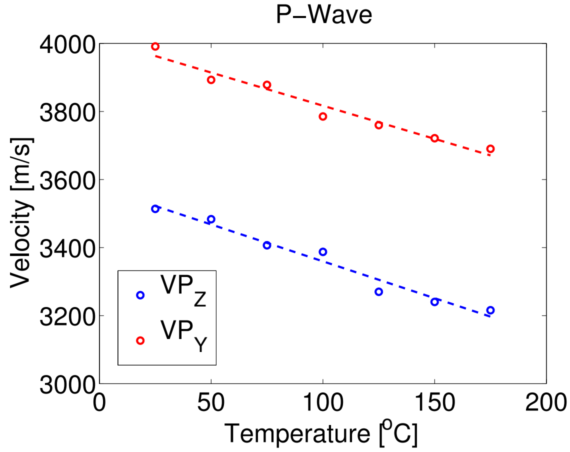

Figure 8: P-wave velocities as function of temperature. The red curve is for propagation in the W-direction, whereas the blue one is the propagation in the Z-direction.

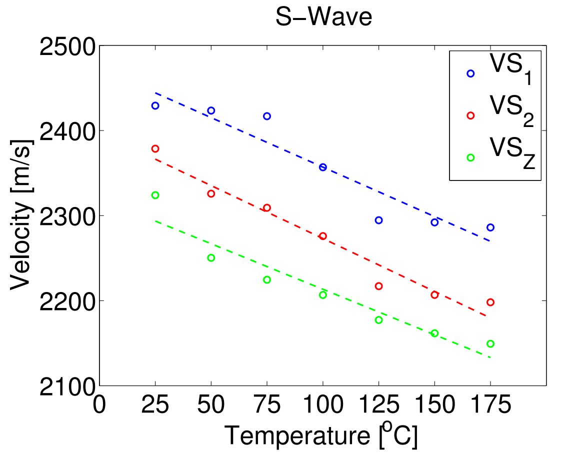

Figure 9: –S-wave velocities as function of temperature. The blue curve is for propagation in the Y-direction with polarization in X, the red one is propagation in the Y-direction with polarization in Z-direction, and the green one is for propagation in Z-direction.

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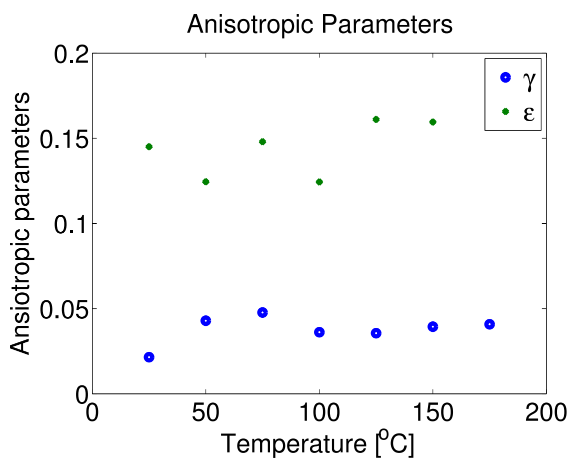

Figure 10: Anisotropic Parameters γ and εs as function of temperature.