A new setup for studying thermal microcracking through acoustic emission monitoring

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ABSTRACT

Thermal stressing has been shown to induce changes in the physical and mechanical properties of rocks. These changes are generally considered to be a consequence of the generation of thermal microcracks and debilitating chemical reactions. The generation of cracks during thermal stressing has been monitored in previous studies using the output of acoustic emissions (AE), commonly used as a proxy for microcrack damage, and from microstructural observations. Here we present a new experimental setup that is optimised to record AE from a rock sample at high temperatures and under a servo-controlled uniaxial stress. This allows for an in-depth study of waveform attributes. Furthermore, this device has the advantage of being able to apply a servo-controlled load on the sample, whilst measuring strain in real time, leading to a spectrum of possible tests combining mechanical and thermal stress. We plan a systematic experimental study of the AE of thermally stressed rock during heating and cooling cycles. The first series of pilot tests were performed on Darley Dale sandstone and Westerly granite.

1. INTRODUCTION

Thermal microcracks are common in nature and can affect the physical properties of rock, including elastic moduli, ultrasonic velocities, permeability, attenuation and strength (e.g. Jones et al., 1997; David et al., 1999; Reuschlé et al., 2003; Vinciguerra et al., 2005; Heap et al., 2013; Siratovich et al., 2015). The mechanics involved may also be analogous to fractured rock at a larger scale i.e. the thermal stressing through heating and cooling of rock in a geothermal reservoir. Thermal microcracks form as a result of thermal stresses due to (1) a thermal expansion mismatch between the different phases present in the material, (2) a thermal expansion anisotropy within individual minerals, (3) thermal gradients across minerals.

Previous laboratory studies have used acoustic emissions (AE) as a proxy for microcrack damage. AE are high frequency elastic wave packets generated by the rapid release of strain energy such as during microfracturing. Here we present a new experimental setup that has been optimised to record AE from a thermally and mechanically stressed rock. We then show preliminary results of thermal stressing experiments on Darley Dale sandstone and Westerly granite.

Understanding the effects of thermal microcracking in rock is of particular interest at a geothermal site, where circulating fluids are at a different temperature to the surrounding rock mass. This is a source of thermal stressing which can, for example, provoke thermal borehole breakouts (Bérard and Cornet, 2003) due to cooling-induced tensile microcracking or can be actively used to enhance the injectivity of geothermal wells.

2. EXPERIMENTAL SETUP

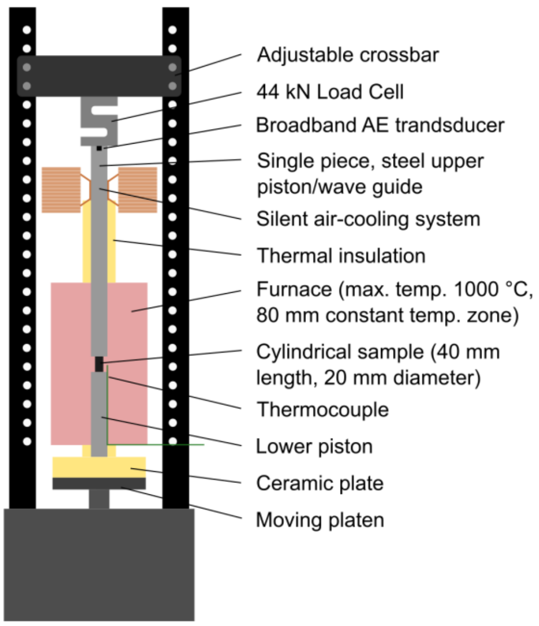

Figure 1: Schematic drawing of the experimental setup at IPG Strasbourg.

Figure 1 is a schematic drawing of the experimental setup. The sample here is a cylinder of 40 mm in length and 20 mm in diameter that is placed between two heat resistant alloy 310 steel pistons. Around the sample is the furnace, capable of heating to temperatures of 1000 °C. The sample is held within the “constant temperature zone” of the furnace to ensure a low thermal gradient along its length. The uniaxial press is a LoadTrac II, which is capable of accurately applying a constant load on the sample, even at low amplitudes of tens of newtons. The load cell is at the top of the frame, and the moving platen is under the lower piston.

Various steps were taken to maximise the quality of the recorded AE signal. Firstly the piston acts as a continuous waveguide made from a single piece of heat resistant stainless steel. We see very little attenuation between the sample and the transducer at the top of the piston. We use a broadband transducer to maximise the frequency content of our recordings and the coupling between the piezo-ceramic and the steel is assured by a spring and a water-based coupling gel. As the response of the piezo-ceramic is sensitive to temperature changes, we use a cooling system between the transducer and the furnace. The cooling system is placed 20 cm above the furnace to limit its influence on the temperature gradient within the furnace itself. The system works by air-cooling two radiators on either side of the piston with silent, high-airflow fans. Heat pipes allow for a maximum heat flow from the piston to the radiators. In practice, the AE transducer remains at temperatures below 30 °C during a test.

The AE transducer is embedded in the top of the piston. To test the choice of embedding the transducer inside the piston, a Hsu-Nielson source (lead break) at the sample was recorded simultaneously by two identical AE sensors. One was attached to the side of the upper piston at the same level as the second transducer that was embedded in the piston, as shown in Figure 1. Figure 2 shows the recorded waveforms and their power spectrum. We see a higher amplitude and broader spectrum of the first arrivals in the case where the transducer is embedded inside the upper piston. This highlights the importance of the transducer location for analysing the recorded waveforms.

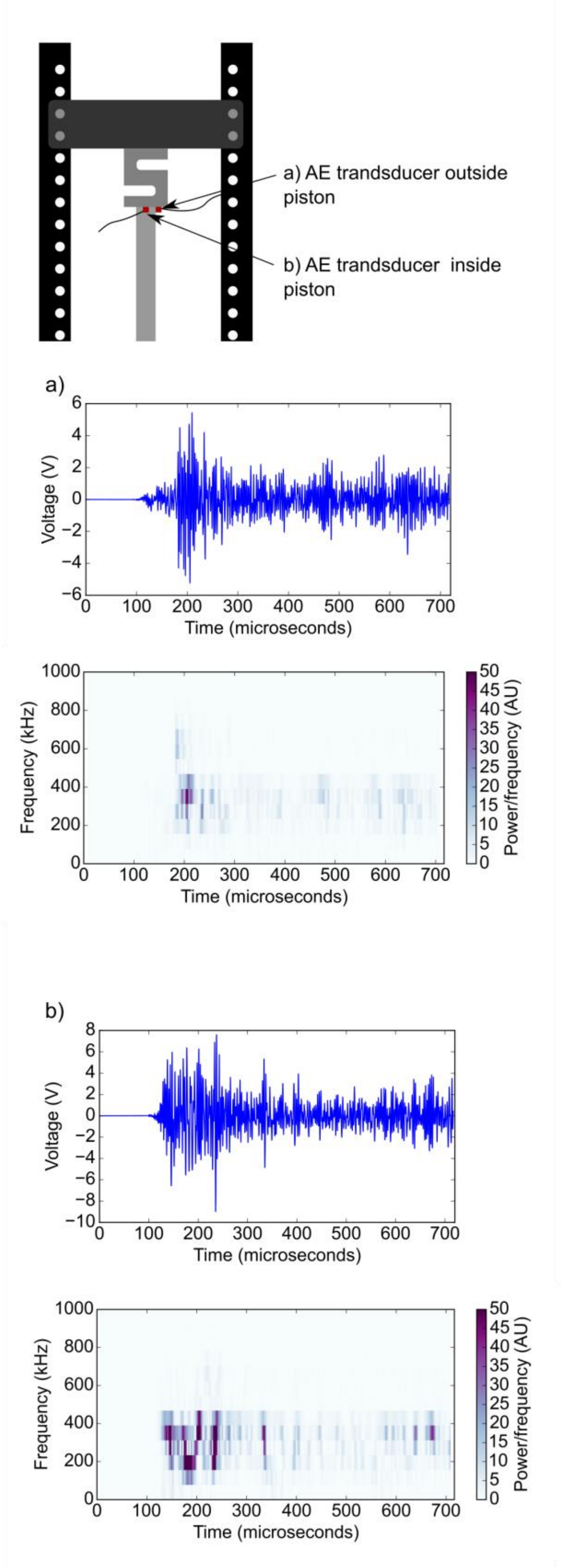

Figure 2: The recorded signals from a Hsu-Nielson source at the sample location, (a) and (b), and their corresponding frequency spectrograms (c) and (d) show how the first arrivals are recorded with a higher amplitude and broader spectrum when the AE transducer is within the waveguide.

3. EXAMPLES OF ACOUSTIC EMISSION DATA

To test the apparatus, we heated Westerly granite to 700 °C at 1 °C/min and under a 1 MPa constant uniaxial load (servo-controlled). The sample remained at 700 °C for a dwell time of 2 hours before being cooled at the same rate of 1 °C/min.

Figure 3 shows the hit rate and the energy rate of the AE released during heating and cooling. We see an increase in the AE hit rate increases with temperature from around 100 °C with a sharp rise at the quartz alpha-beta transition (~573 °C). This is due to the volume increase as the quartz undergoes the phase change (Glover et al., 1995). We see that most of the recorded acoustic energy is released during cooling (Figure 3).

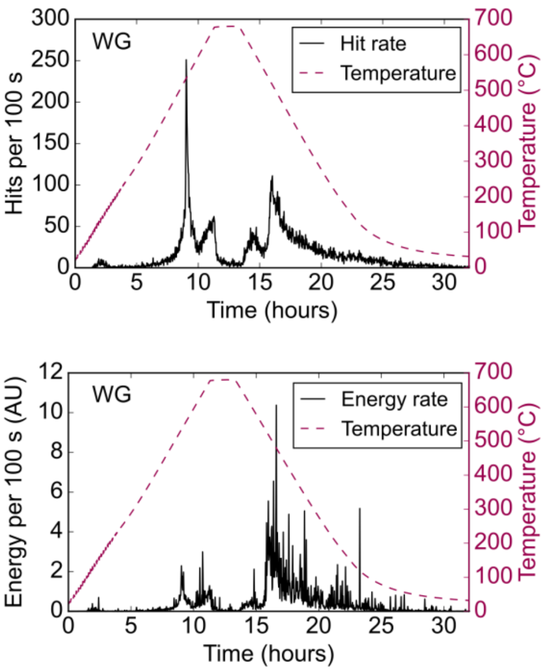

Figure 3: The AE hit rate and energy rate per 100 s during the heating and cooling of a Westerly granite sample to 700 °C under 1 MPa uniaxial load.

The same procedure was carried out on Darley Dale sandstone. It was heated to 700 °C at 1 °C/min and 1 MPa constant uniaxial load (servo-controlled). Figure 4 shows a hit rate which increases with temperature from around 100 °C, as with the granite. There is also an increase in the hit rate at the alpha-beta transition, however it is less distinct for the sandstone. This time most of the recorded acoustic energy is released during heating.

3. CONCLUSIONS AND OUTLOOK

The presented apparatus was designed for the AE monitoring of thermally and mechanically stressed geomaterials. Preliminary results show AE activity during heating and cooling in two rock types.

Future efforts will be concentrated on the analysis of the recorded AE waveforms themselves to try and understand their source mechanisms. This involves deconvolving the response of the system to better compare AE events when the sample is under different thermal stress conditions. Other tests carried out on this setup will include cyclic heating experiments and thermal stressing under variable uniaxial loads.

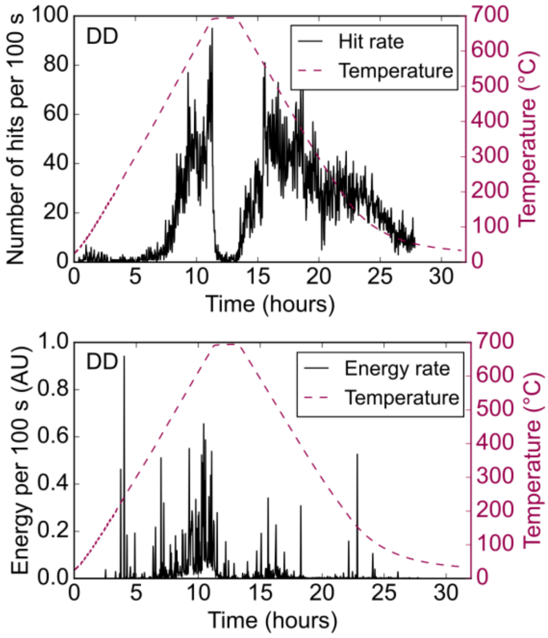

Figure 4: The AE hit rate and energy rate per 100 s during the heating and cooling of a Darley Dale sandstone sample to 700 °C under 1 MPa uniaxial load.

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