Phenomenological description of acoustic emission processes during high-pressure sand compaction

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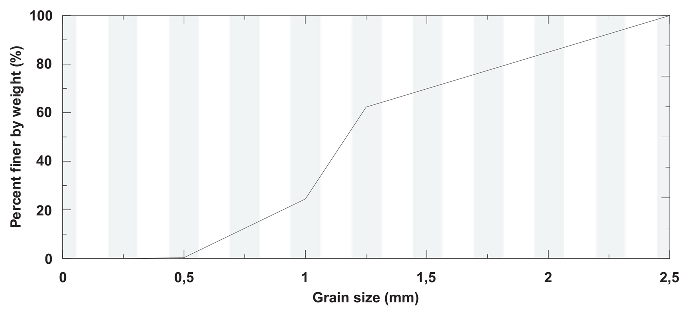
Introduction

Granular materials submitted to uniaxial compression suffer a pore space reduction due to mechanisms such as particle rearrangement and grain crushing. These changes in the internal structure of the material release energy in the form of elastic waveforms that can be detected by sensors sensitive to acoustic emission. The purpose of this study is to identify the different phenomena produced during high-pressure sand compaction by analyzing the acoustic signals generated along the process. Particle movement, grain failure, friction between grains and the surface of the compression container as well as intergranular friction were studied. Decrepitation of fluids inclusions was also evaluated to temperatures up to 100 ºC.

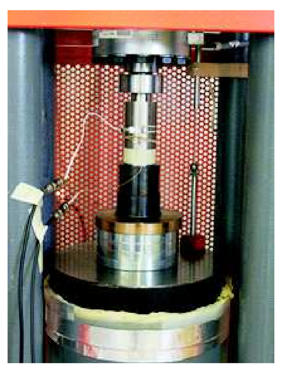
Equipment



Grain size distribution curve of silica sand.

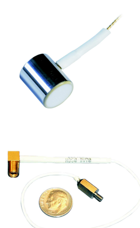
Compression device.

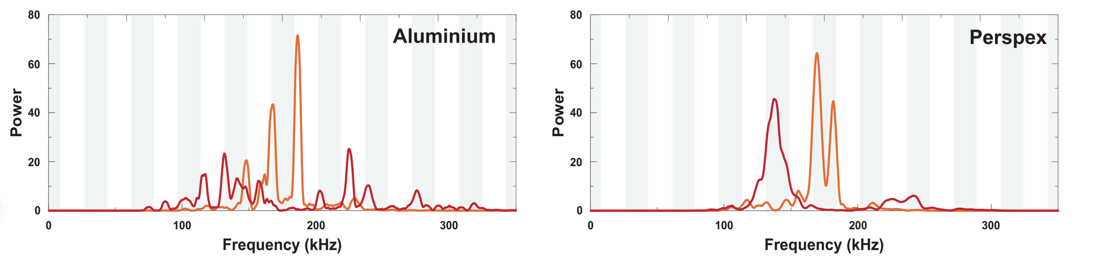
Silica sand was used in this study. Its grain size distribution curve is shown in the left figure. The sample was compacted in a cylindrical compression container made of stainless steel with an outside diameter of 55 mm and an inside diameter of 35 mm. In compression tests, the total height of the sample in the container was 10 mm, equivalent to about 13 g.



Hydraulic press.

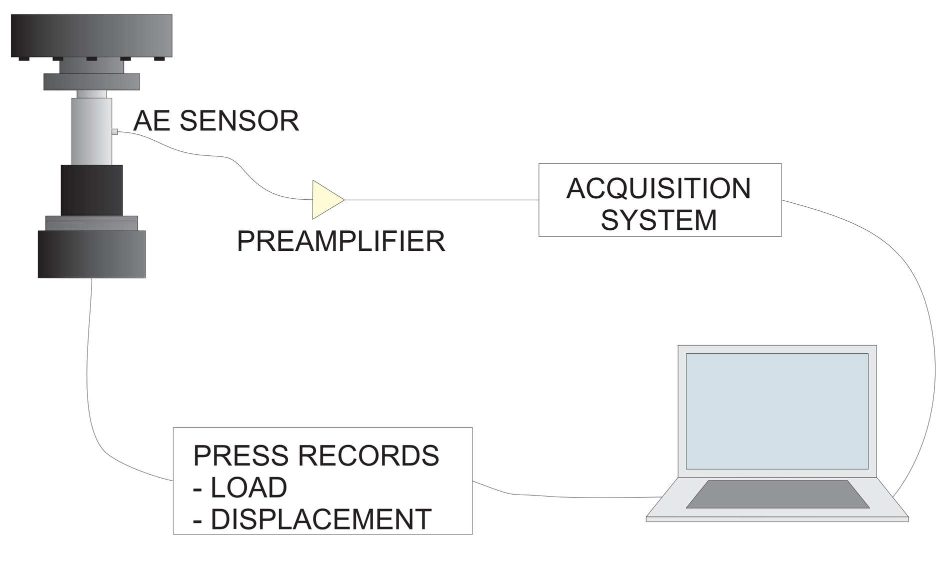
Tests were carried out in servocontrolled hydraulic press and PCD2K multi-channel controlling system. PAC Micro200HF and HD50 AE Sensors were attached to the compression device.



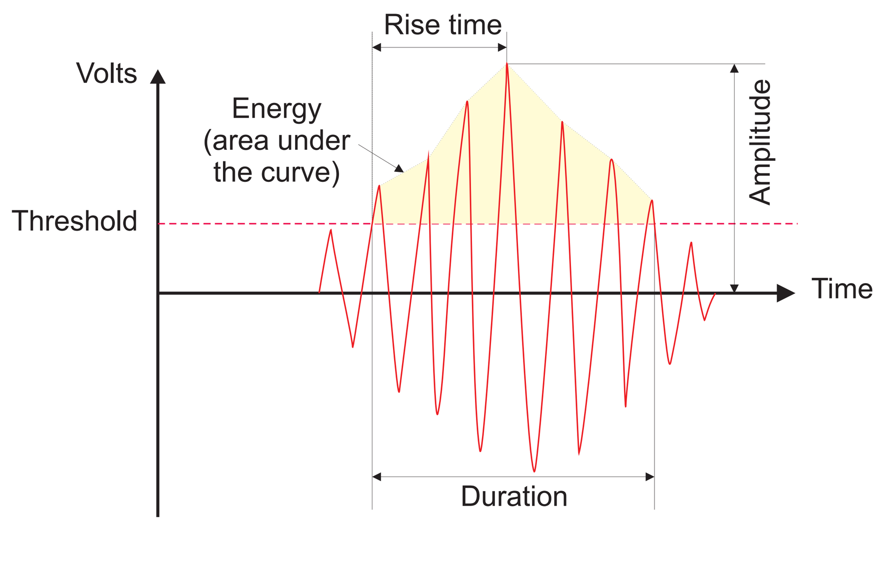


Power vs frequency tests performed with the Micro200HF (dark brown) and HD50 (light brown) sensors. To test the quality of the sensors, a pencil lead with a 0,5 mm diameter and a 2H hardness was broken by pressing against an aluminium (left) and perspex (right) surface to simulate acoustic emission.

Terminology



AE System

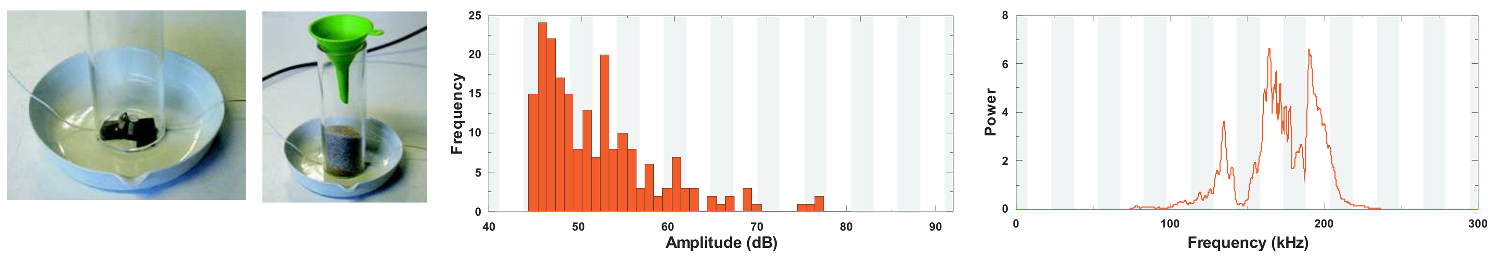


AE signal and AE parameters

Process identification tests

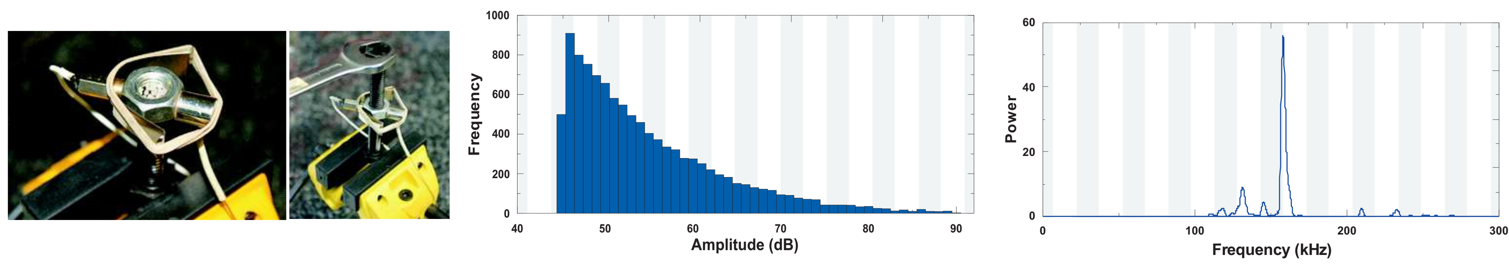
Particle movement

Both AE sensors were placed at the bottom of a perspex tube which was later partially filled with sand. Particle movement was simulated by causing a sand flow over the sensors as the cylinder was slowly lifted.



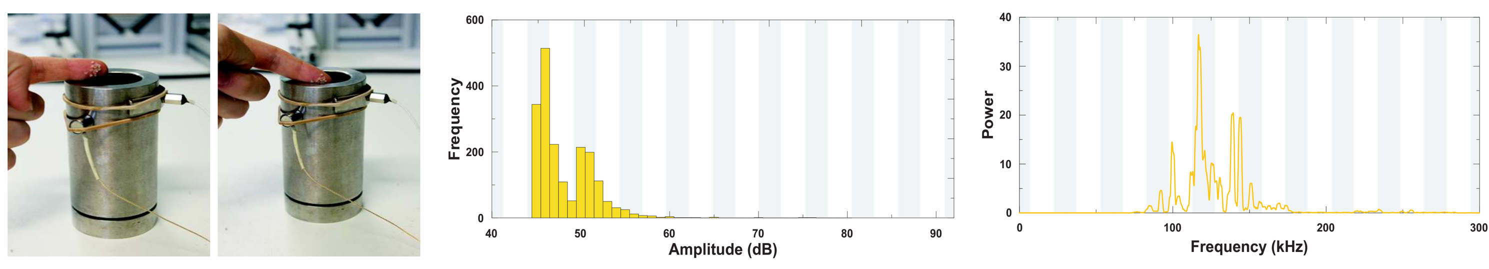
Grain breakage

Grain crushing was induced by tightening a screw with a wrench against a thin monolayer of grains placed inside a nut. Two sensors were attached to the nut in order to record acoustic emissions produced in the test.



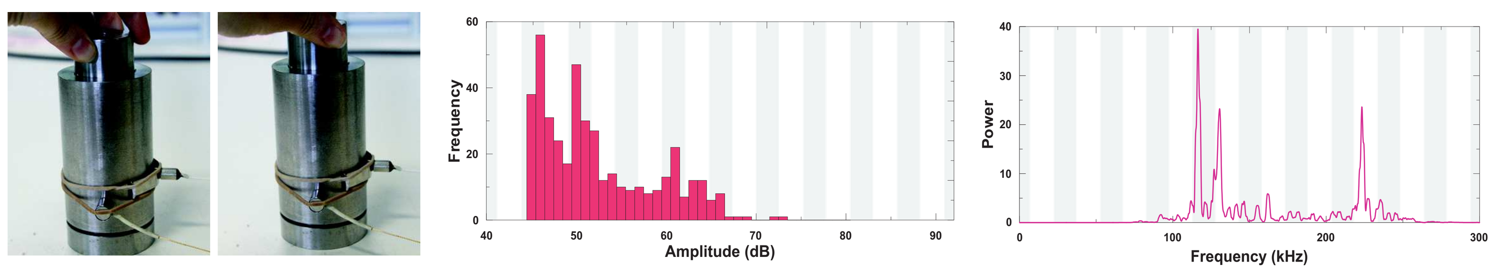
Grain-container friction

The method proposed to estimate this sort of friction consist in rubbing a few grains of sand against the inner surface of the compression container using a finger. The AE sensors were located close to the area where the friction was taking place.



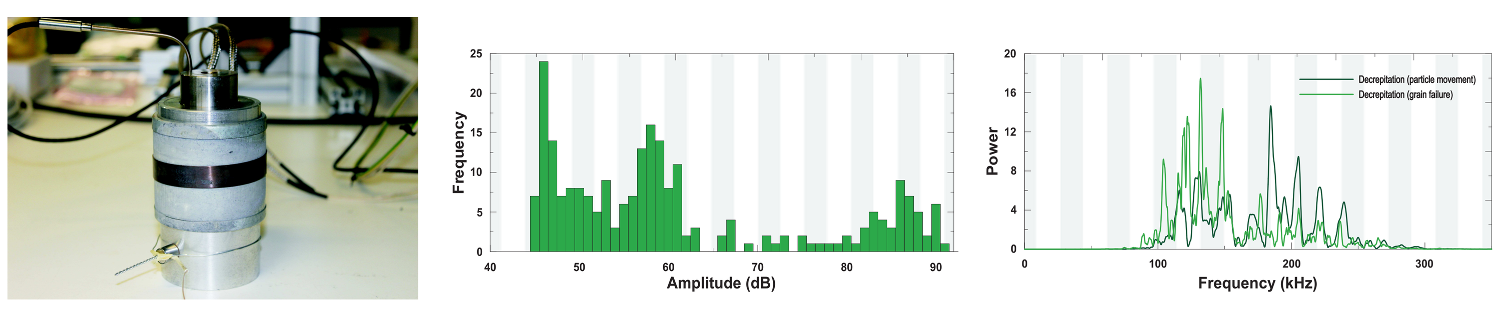
Intergranular friction

Intergranular friction was caused by carefully rotating the piston inside the compression container, which was firstly filled with a layer of sand. The AE sensors were attached to its external surface by using a rubber band.



Decrepitation of fluid inclusions

Decrepitation of fluid inclusions was also evaluated for high temperatures. For this purpose, the compression container was filled with sand and a resistor was placed over its external surface in order to generate heat. In this case, the AE sensors were fixed to the container by using a steel wire. AE signals were recorded for temperatures up to 150 ºC.



High-pressure compression tests

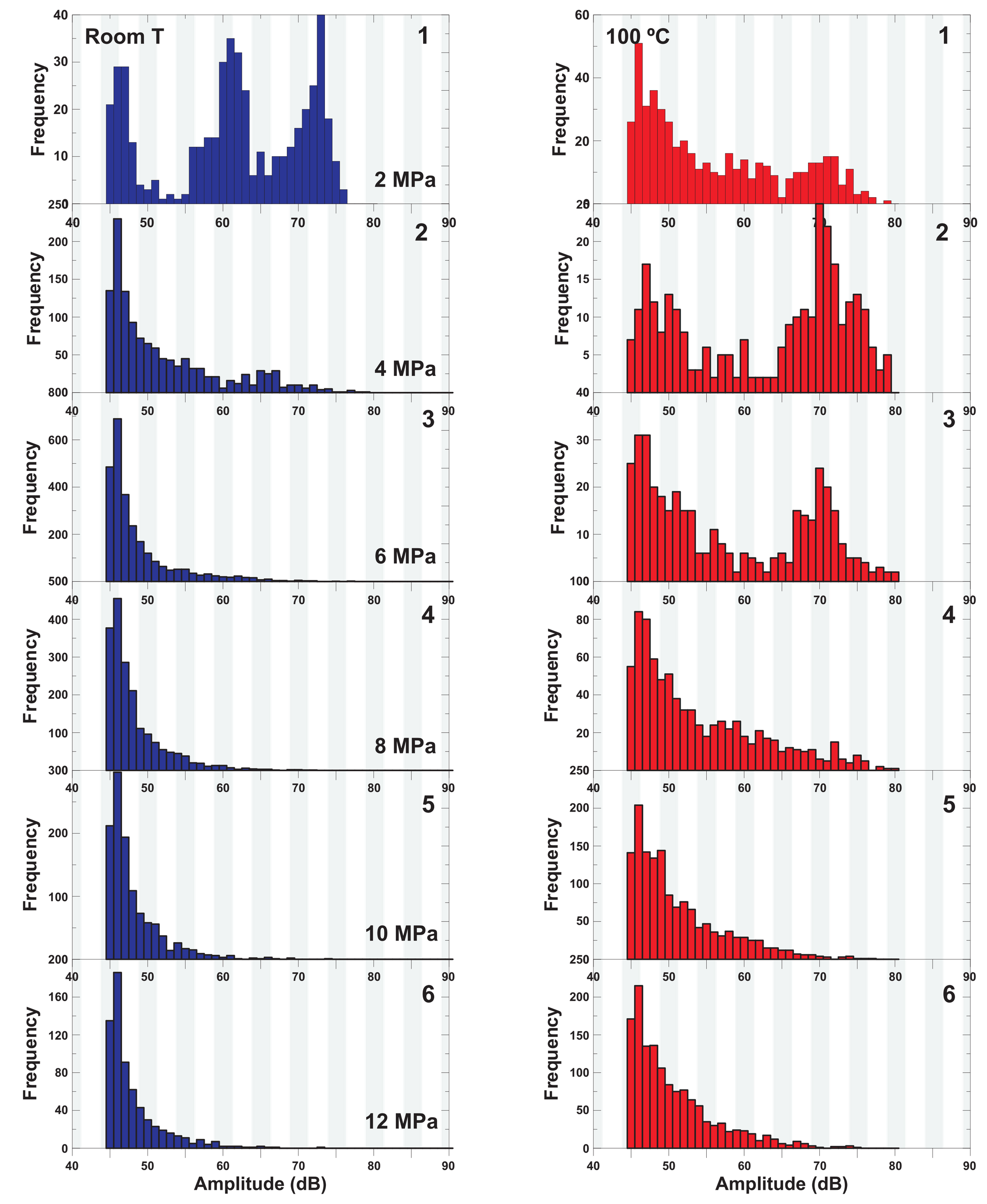
We performed uniaxial compression tests on sands using acoustic emission (AE) methods to detect the onset of breakage. Force and displacement were measured together with the corresponding AE signals.

The testing program consisted of 1-D compression tests up to a pressure of 122 MPa (12t) with temperatures up to 100ºC. Each 1-D compression test consisted of a loading/unloading path, each one made of 6 stages. Pressure was stepwised rised at different rates and for different temperatures (up to 100ºC) in 2 ton stages. After each compression step, pressure was hold constant during 120 s to minimize the effect of deferred phenomena.

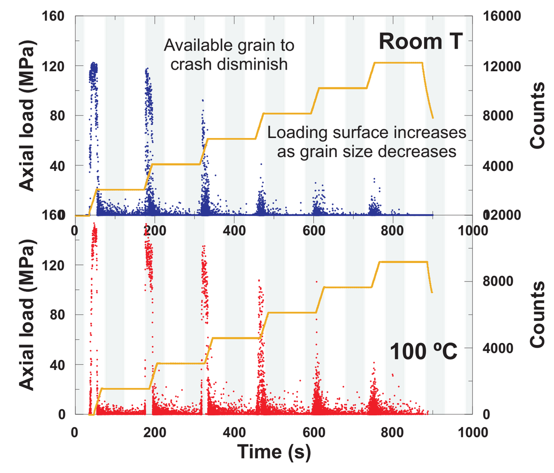
The threshold for AE events was set to 45 dB and pre-amplifier at 40 dB. The AE sensors were placed at the external surface of the compression device, by using a rubber band for room temperature tests, or a steel wire for 100 ºC tests.

Experimental setup showing AE sensors attached to the compression device prepared for the test.

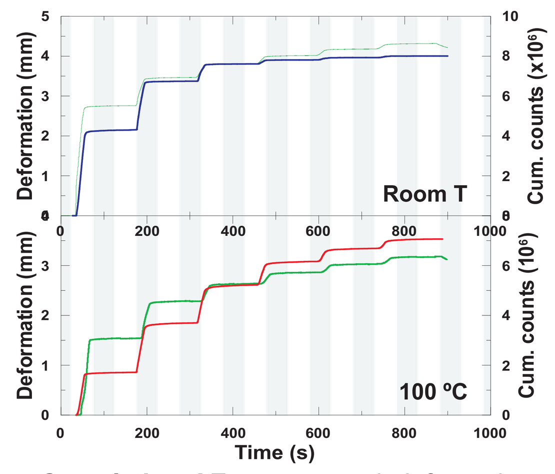
Results



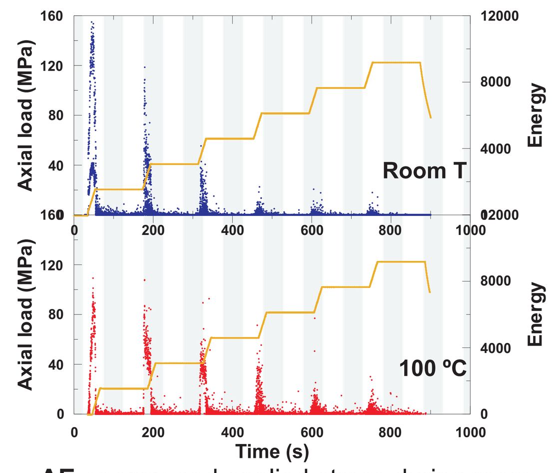
Amplitude distribution histograms of all the events generated during each of the six stages of the testing process, both for room temperature (left) and 100ºC (right).



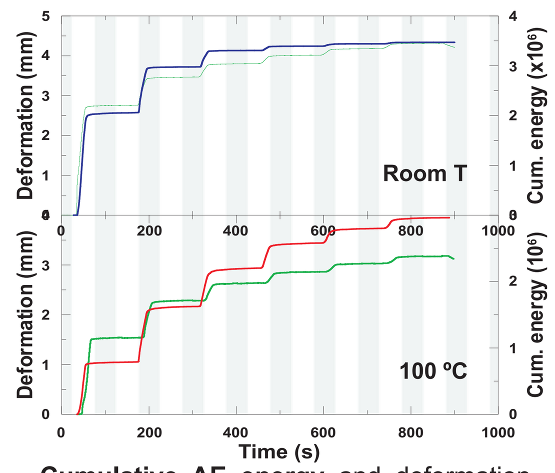
AE counts and applied stress, as a function of the time, during compaction tests (room temperature and 100ºC).



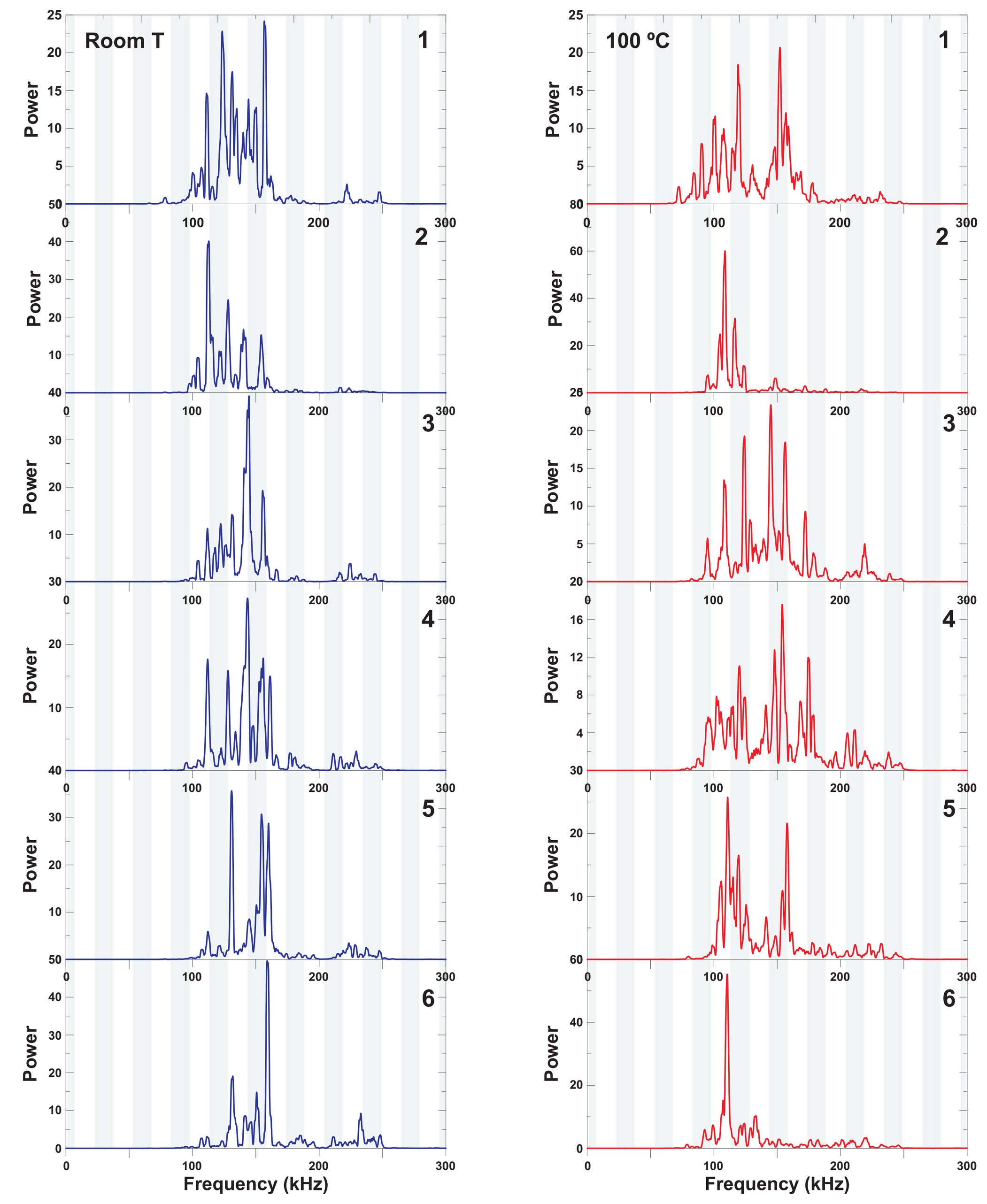
Cumulative AE counts and deformation obtained during both compaction tests (room temperature and 100ºC).



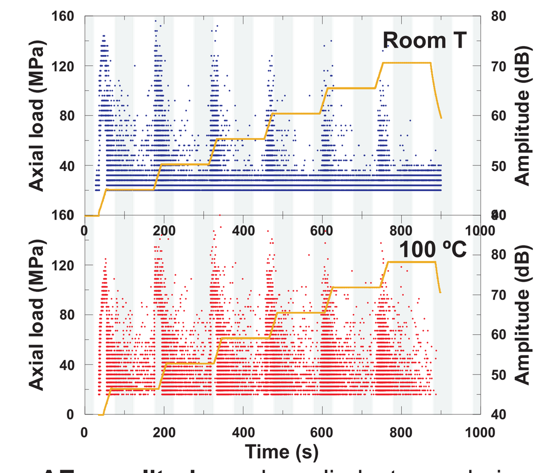
AE energy and applied stress during room temperature and 100ºC compaction tests.



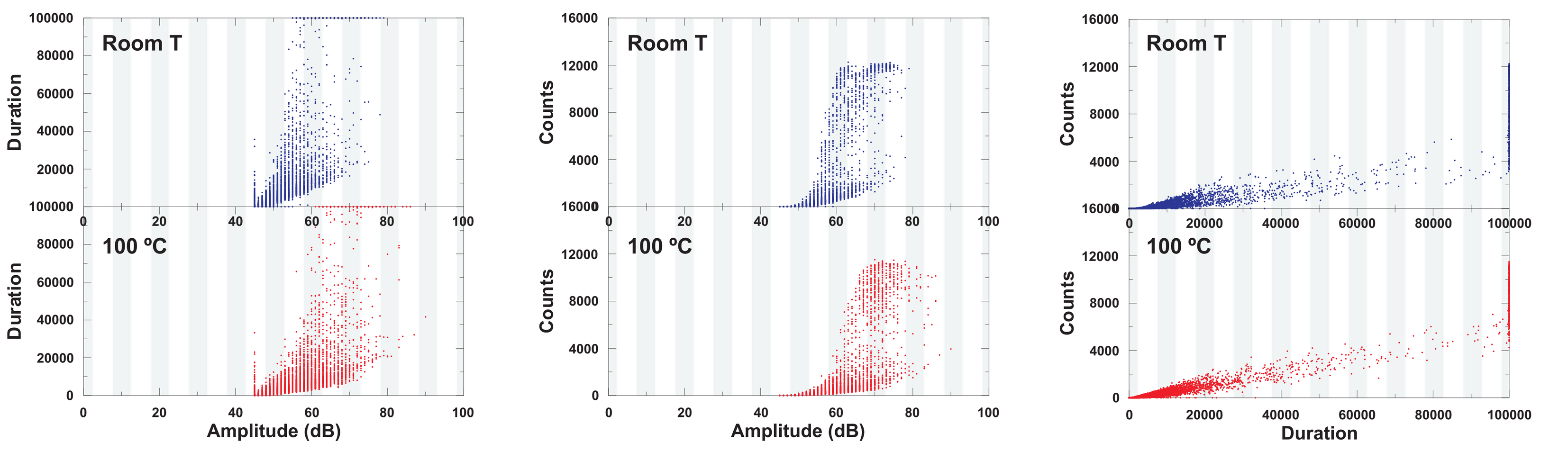
Cumulative AE energy and deformation during room temperature and 100ºC tests.



Power vs frequency graphs for each of the six stages of the testing process. Fast Fourier Transformations were used to transform waveforms from the time to the frequency domain, both for room temperature (left) and 100ºC (right).

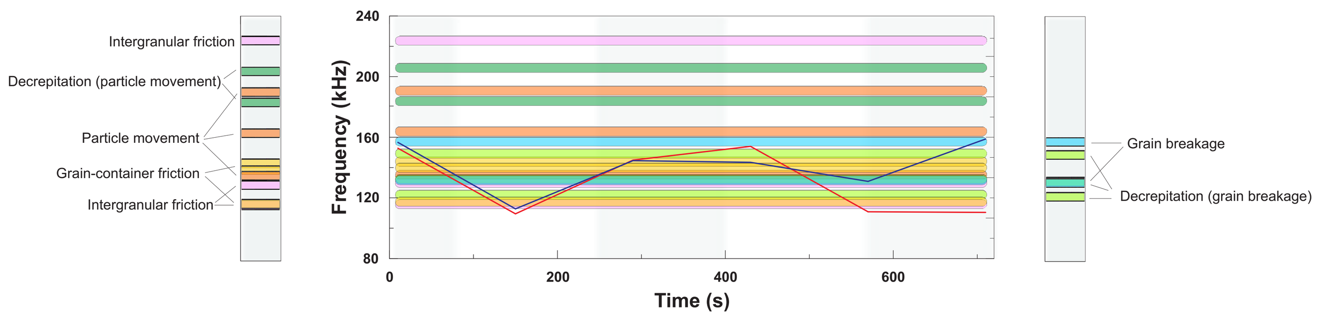


AE amplitude and applied stress during room temperature and 100ºC tests.



Duration vs amplitude, counts vs amplitude and counts vs duration crossplots of AE signals detected during the testing. The upper graphs show the results for room temperature, while the lower figures show those for 100ºC.

Conclusions



Main frequencies for each stage of high-pressure compression tests are shown using blue (room temperature) and red (100ºC) lines.

Comparative of results obtained with different AE features

STAGE	ROOM T Frequency	ROOM T Amplitude	ROOM T Counts	ROOM T Energy	100 ºC Frequency	100 ºC Amplitude	100 ºC Counts	100 ºC Energy
1								
2								
3								
4								
5								
6								

Grain breakage (represented in orange) can be detected up to the second stage at room temperature and up to the fourth stage at 100ºC when analysing AE frequencies, amplitudes and energy. However, in both cases the results of AE counts showed a spread of this phenomenon up to an additional stage.

The conclusions based on AE results are as follows:

1. At room temperature, grain failure was acoustically detected for axial loads up to 40 MPa (2nd stage of the test). However, at 100ºC, this phenomenon can be identified for loads up to 80 MPa (4th stage). This additional breakage of sand particles at higher temperatures could be explained by the decrepitation of fluid inclusions, which also produces grain crushing.

2. Grain breakage caused by decrepitation of fluid inclusions could also be detected in duration vs amplitude crossplots, since short (low duration) and strong (high amplitude) hits associated with grain crushing became more important for the test performed at 100ºC.

3. Cumulative AE counts and cumulative AE energy showed high similarity with deformation curves at room temperature. Therefore, analysis of AE activities in sand is helpful to assess the settlement.

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