Effect of temperature on the mechanical behavior and acoustic emission characteristics of a rock – like material

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ABSTRACT: Acoustic Emission (AE) is a non – destructive testing technique that allows the recording of the elastic waves released during crack propagation when materials are subjected to different stresses. Most of the current research evaluates AE characteristics related to mechanically stressed materials. However, there are hardly any references to studies that target how thermal or thermos – mechanical stresses influence AE recordings. Consequently, an experimental campaign has been designed to characterize high–strength mortar specimens, subjected to different temperatures while performing simple compression tests and monitoring the AE. The research has allowed obtaining interesting results in line with the objectives set for this study. Thus, it has been possible to establish that: 1) temperature affects the simple compressive strength of the material studied, 2) the recording of AE associated with thermal stresses is possible and 3) the combination of thermal and mechanical stresses increases the recording of AE parameters.

Keywords: Acoustic Emission (AE), thermo-mechanical stresses, crack propagation, temperature.

1 INTRODUCTION

Acoustic emission (AE) is a non-destructive technique that allows the monitoring of the elastic waves generated during crack propagation in materials subjected to different stresses. Its main interest lies in the fact that it enables continuous monitoring of the tensional state of the material (Boniface et al., 2020).

Currently, this technique is acquiring great relevance in the field of engineering, especially for the characterization of materials, such as mortars, concretes or rocks, subjected to mechanical stresses (Verstrynge et al., 2021). Thus, the analysis of the different parameters of the AE waves allows to differentiate the moments of greatest plastic deformation, to understand the fracture process and to evaluate the general state of the material at each moment (D. G. Aggelis et al., 2013).

The mechanical stresses to which materials are subjected are important in assessing the safety and failure mechanisms of structures. However, so are thermal stresses, generated by fires, thermal gradients, or other phenomena, since they also affect the mechanical properties of materials (Yanjie et al., 2022). Despite this, only some research which focused on how temperature affects damage evolution in materials such as rocks (Zhang et al., 2020) has been found.

Therefore, the purpose of this paper is to present the results of an experimental campaign in which the mechanical and physical properties of a high-strength mortar, subjected to different temperatures, were analyzed by means of simple compression tests while recording the AE generated.

2 EXPERIMENTAL PROCEDURE

The objectives of the experimental campaign designed were threefold: (a) quantify the effect of temperature on the simple compressive strength of the material, (b) determine if AE associated with thermal stresses can be recorded and (c) evaluate if there is a greater recording of AE while the material is subjected to both thermal and mechanical stresses. For this purpose, the following experimental procedure was performed.

2.1 Sample preparation

Initially, the specimens to be tested were prepared. It was decided to use mortar, as it is a material that behaves homogeneously in mechanical terms, which facilitates the analysis of the study variables. To facilitate the placement of the AE sensors during testing, it was decided that the specimens would be prismatic, according to (American Society for Testing and Materials, 2014) specifications, with dimensions of 51x51x110 mm.

The high-strength mortar used in the test specimens has a cement - sand - water ratio of 1:1:0.43. High-strength grey cement (CEM I 52.5 R) and sand with a particle size of less than 2 mm were used. The mixing process consisted of mixing the three previously mentioned elements progressively with a mixer for 15 minutes. Finally, to avoid the formation of cracks, the mixture was vibrated. The curing of the mortar lasted 28 days in a humidity chamber that allowed maintaining a constant temperature and humidity.

2.2 Physical characterization

After curing, the specimens are divided into two groups: A, specimens to be tested at room temperature (standard) and B, specimens to be tested at 50ºC. They were then physically characterized (Table 1) through their density and velocity of elastic waves.

Table 1. Summary table of the physical properties of the tested specimens.

Specimen	ρ [g/cm^3]	V_P (m/s)	Specimen	ρ [g/cm^3]	V_P (m/s)
1A	2.1	3,677	1B	2.0	3,610
2A	2.2	3,509	2B	2.2	3,610
3A	2.0	3,571	3B	2.1	3,534
4A	2.1	3,623	4B	2.2	3,584
Mean	2.1	3,595	Mean	2.1	3,585
Average deviation	0.1	62	Average deviation	0.1	31

2.3 Experimental campaign

The experimental campaign designed is intended to evaluate the difference in the behavior of the high-strength mortar at room temperature (19.5ºC) and at 50ºC.

The heating of the specimens is performed using a carbon steel heating plate with three heating cartridges that allow reaching a heating power of 1,500W. The heating temperature of the plate is controlled by a COMET Datalogger data acquisition and recording unit through a thermocouple. To prevent thermal leakage during the heating process, the specimens are thermally insulated with a rock wool insulating structure.

The test procedure is as follows. The COMET is programmed so that the plate reaches a maximum temperature of 60ºC. The test specimen is left to heat for two hours. After this time, a thermographic camera is used to check that the temperature of the test specimen is the desired one (50ºC) and constant along its entire surface. Then, both the test specimen and the plate are place on the platen of a universal press, to maintain a constant temperature and the application of thermal stresses during the test. The AE sensors are placed, using honey to facilitate the transmission of the elastic waves from the material to the sensors, and the sensors are fixed with insulating tape. This procedure is carried out as quickly as possible to avoid the cooling of the specimen. In total, two AE sensors were used, with sensor 1 (S1) always placed on the right and sensor 2 (S2) on the left (Figure 1). The recording of AE has followed the (Normalización, 2011).

Figure 1. Test readiness during testing.

In the case of tests at 50ºC, the AE recording starts before the loading process begins, to try to record thermal stresses events. After allowing a period of 40 seconds and, if no relevant AE associated with thermal phenomena has been recorded, the load is applied, at a rate of 1 MPa/s.

3 RESULTS

After testing, the first step was to determine the simple compressive strength. The values, both individual and average, are shown in Table 2. At room temperature, the simple compressive strength of the high-strength mortar is 51.9 MPa. However, after a temperature increase (ΔT) of 30.5°C from room temperature (19.5ºC), there is a reduction of this parameter by 23.7% (39.6 MPa).

Table 2. Summary table of the physical properties of the tested specimens.

Specimen	σ_c [MPa]	Specimen	σ_c [MPa]
1A	55.5	1B	37.7
2A	56.2	2B	51.9
3A	49.2	3B	34.8
4A	46.8	4B	33.8
Mean	51.9	Mean	39.6
Average deviation	4.0	Average deviation	7.3

The fact that increasing temperature decreases the simple compressive strength of the material is consistent with the results obtained in other investigations, such as that of (Yanjie et al., 2022). However, (Yanjie et al., 2022) obtains only a 10% decrease in this parameter. This difference with the results of the present investigation can be justified by the use of different proportions and elements when generating the concrete mixes and a different method of applying the thermal gradient.

The characteristic of the recorded EA is next to be analyzed. For this, hits and energy are selected as study parameters. The former are the signals received by a sensor for a particular AE event, while the latter is the energy associated to deformation and is usually presented in dimensionless form

(Dimitrios G. Aggelis, 2011). Figure 2 shows in the same graph the stress - time curve, with the corresponding distribution of the hits recorded by each of the sensors used, when the specimens of group A ($T = T_{ROOM}$) were tested. Initially, a high number of hits are recorded, because of the coupling process of the press plate with the specimen surface. Then, the number of hits decrease, observing some peaks (case of specimen A1) that are probably due to the appearance of isolated microfractures. Finally, a sharp increase in both sensors is noted when the process of breakage due to coalescence of microfractures begins. In this case, the range of maximum values of hits recorded oscillates between 200 and 240.

The pattern previously described is shared by the specimens tested at a temperature of 50ºC (Figure 3). It should be noted that, on two occasions, it was possible to record AE events associated exclusively with fracturing processes generated by thermal stresses (specimens B2 and B4). The range of hits recorded for this study group (240 - 290 hits) is 20% higher than the study group at room temperature.

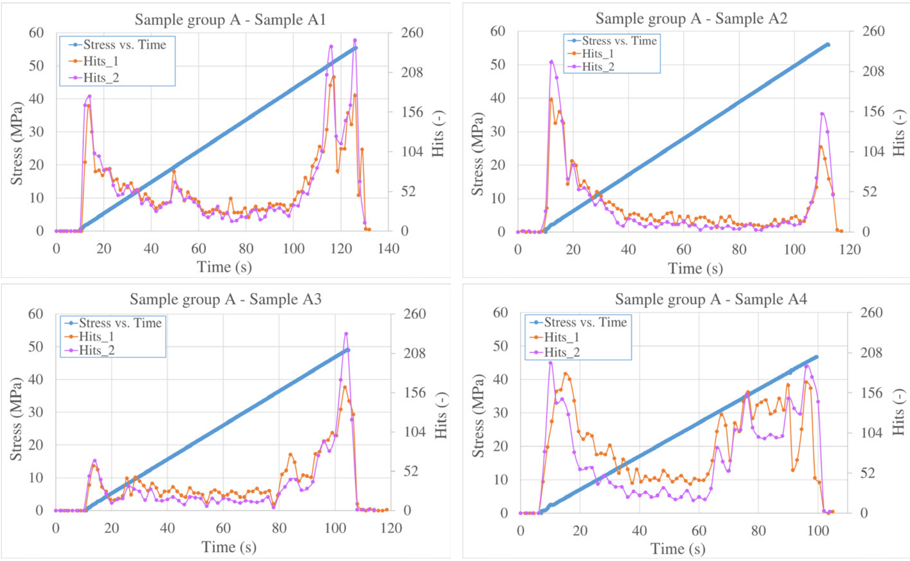

Figure 2. Stress - hits - time graphs for $T = T_{ROOM}$.

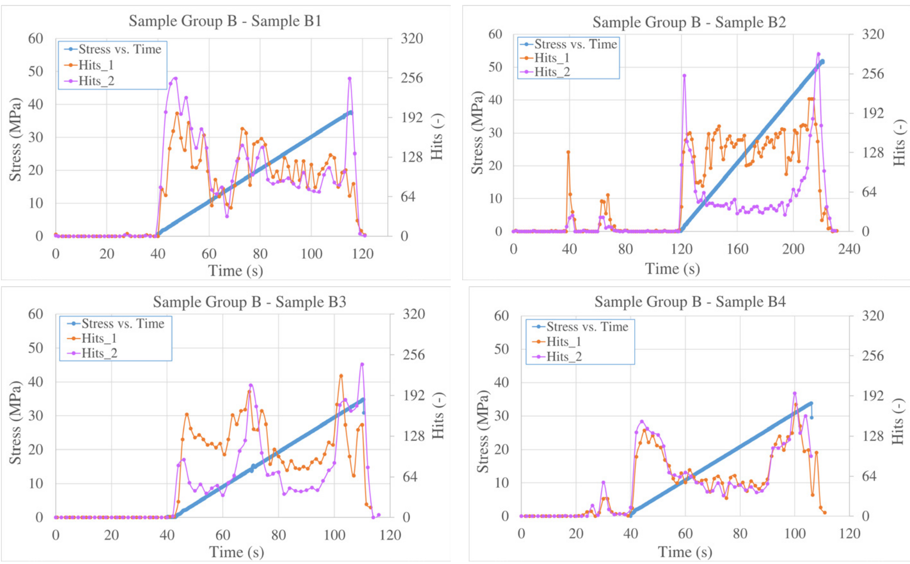

Figure 3. Stress - hits - time graphs for T = 50ºC.

Regarding the energy released per event, it can be observed that, in both cases, the largest energy peaks occur either at breakage or immediately after. For the tests at room temperature (Figure 4), small energy peaks could also be noted during the coupling between the press disc and the specimen and moments before breakage occurs. Except for the first test, in which energies of 25,000 in S1 and 40,000 in S2 were recorded, for the rest of the specimens the recorded range oscillates between 15,000 and 25,000 in S1 and 10,000 and 25,000 in S2.

At 50ºC (Figure 5), the range of energies recorded for S1 was uneven, since for one test an energy of 20,000 was recorded, while in another it was 85,000. In the case of S2, the energies measured were similar to the previous study group's results, with an average value of 20,000. In addition, in the energy peaks, resulting from the coupling between disk and specimen, higher energies were recorded (10,000 on average) compared to the former case (2,500). Therefore, once again, it is observed that the joint effect of thermal and mechanical stresses increases the AE recorded with respect to that recorded when only mechanical stresses are being generated.

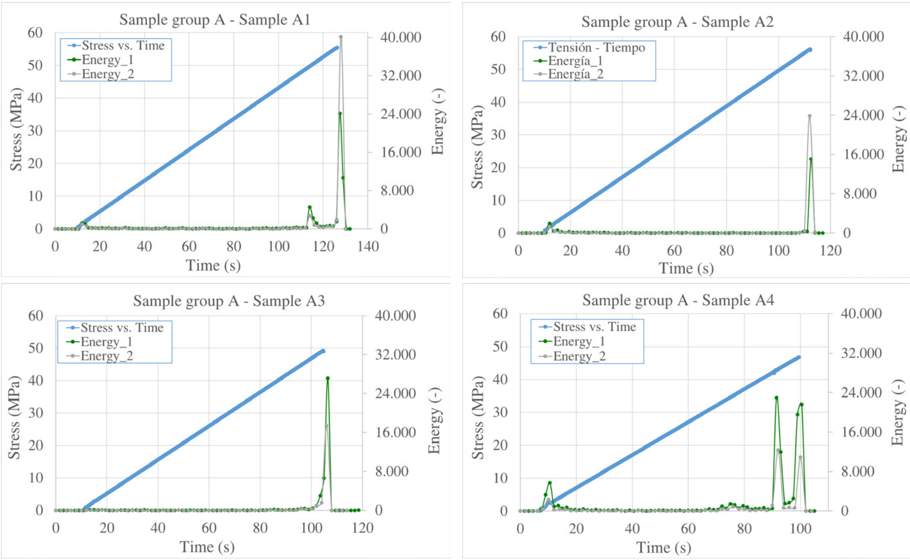

Figure 4. Stress - events - time graphs for T = T_{ROOM}.

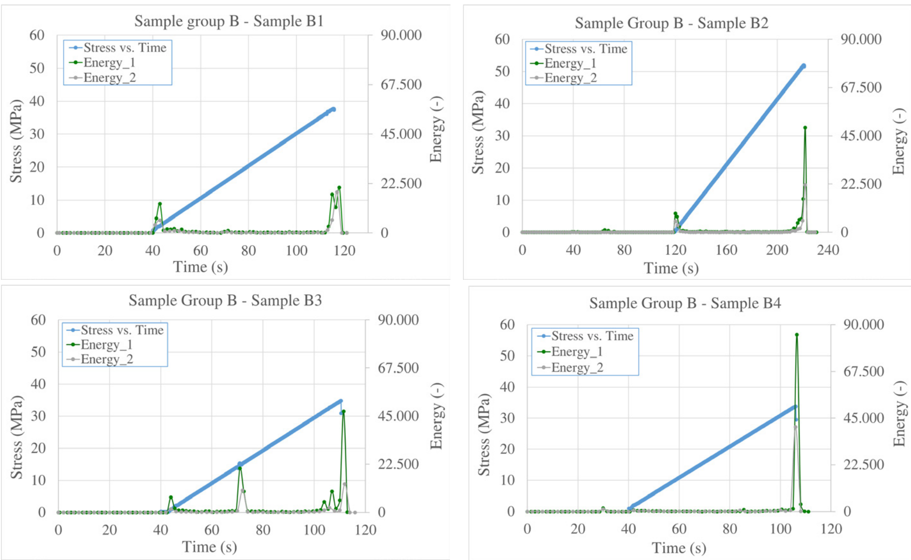

Figure 5. Stress - events - time graphs for T = 50ºC.

4 CONCLUSIONS

This paper describes an experimental campaign whose main objectives were threefold: (a) to quantify the effect of temperature on the simple compressive strength of a high-strength mortar, (b) to establish whether it is possible to record AE events associated with thermal stresses, and (c) to evaluate whether there is a variation in the recording of AE events when the material is subjected to higher thermo-mechanical stresses.

For this purpose, a series of prismatic specimens were prepared, with dimensions 51x51x150 mm, according to ASTM C 170 - 90. After 28 days of curing, specimens were physically characterized. Subsequently, they were tested at room temperature and at 50ºC by means of simple compression tests, simultaneously recording the EA generated.

The conclusions drawn from the analysis of the results are: (1) the high-strength mortar generated has a very homogeneous behavior, since its average density is 2.1 g/cm3 and its wave propagation speed is 3590 m/s; (2) after performing simple compression tests in a universal press, the simple compression strength at room temperature is 51. 9 MPa, while the simple compressive strength at 50ºC decreases to 39.6 MPa, i.e. there is a reduction of 23.7 %; (3) in the tests performed at 50ºC, AE events associated exclusively with thermal stresses were recorded; and (4) when the specimens were subjected to thermal and mechanical stresses simultaneously, there was an increase in the hits and energy recorded, with respect to the standard values (room temperature).

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