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Analysis of Damage of Reinforced Mortar by Non-Destructive Methods

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Abstract:
The aim of this study is the improvement of the potential of coupling between non-destructive methods on damage characterization of mortar (acoustic emission and ultrasound).
The mortar is a very heterogynous material, in which damage can be estimated by the method of the ultrasounds. It is also fragile, which allows to have intense signals by the technique of acoustic emission.
The results obtained on this paper concern the reinforced mortar by steel fibres, show that damage can be describe in three stages of damage. Stage 1, where there is no acoustic activities, stage 2, correspond the increase of the attenuation according to the increase of the value of the applied strength. This value depends very strongly on the applied strength, then the strength is strong, the attenuation is important. The value of the attenuation in the case without load is very different from that observed just before the failure in third stage.

Keywords Mortar, Acoustic emission, Ultrasound, Attenuation, Damage.

دراسة الضرر الحادث في المونة المقواة بواسطة الطرق غير الهدامة للبنية

يهدف البحث لدراسة استخدام تقنية الموجات الفوق صوتية والانبعاثات الصوتية الناتجة عن الشقوق والكسر في المركبات الإسمنتية (المونة).تمت الدراسة على خلطة المونة والاضافات المعدنية، ووضحت النتيجة إنه يمكن تتبع تطور الشقوق والكسر حتى انهيار العينة بواسطه التقنيات السابقة، وأن التصرف العام حتى الكسر يمكن أن يتمثل بثلاث مراحل حسب القوة المطبقة وهذه المراحل واضحة ويمكن ملاحظتها من خلال التقنيات المدروسة.

كلمات مفتاحية: المونة، الانبعاث الصوتي، الموجات الفوق صوتية، تقليل من القوة، الضرر.

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1. Introduction:

The progression of cracks in concrete elements is monitored in situ by diffuse ultrasound, in a novel application of this technique.

Goszczyńska [1] shows that it is possible to detect and locate themicro-cracks (not visible on the member surface) and growth of cracks, which are visible on the element surface.

Huet al.[2] show that acoustic emission system could well reflect the internal defects and cracks of the specimen. Additionally, the results illustrated that acoustic emission (AE) technology could reflect the initial fracture moment and final structure failure at a relatively low loading rate, and consequently could acquire the initial and failure fracture loadings. Based on this limited study, it can be found that, in most cases, the characteristic of concrete AE parameter could reflect the concrete crack propagation and its complete structure failure during the loading procedure. Additionally, it was found that the results from AE method were similar to those from strain gauge method.

Elferganiet al. [3] show that the use of Acoustic emission is a good tools for the detection of damage in concrete.

Kenny et al. [4] show that the calibrated Weibull rupture probability functions with AE event data can be applied to study damage processes under mechanical loading for brittle materials such as concrete.

Suzuki et al.[5] show that the decrease in mechanical properties could be evaluated by acoustic emission with the durability index, both of which are affected by internal cracks generated. Thus, the damage of concrete structures is quantitatively evaluated by AE and X-ray computed tomography method.

Shah et al.[6] show that the correlation between acoustic emission and nonlinear ultrasonic techniques in assessing damage growth in concrete was investigated.

2. Methodology:

Both Non-Destructive (acoustic emission and ultrasound) methods can be used to evaluate damage in mortar. The correlation between results from acoustic emission and ultrasound in tensile tests for mortar prepared with steel fibres manifest, is a new method for identification damage and failure in materials especially in our case the mortar.

3. Experimental procedures:

3.1. Mechanical testing:

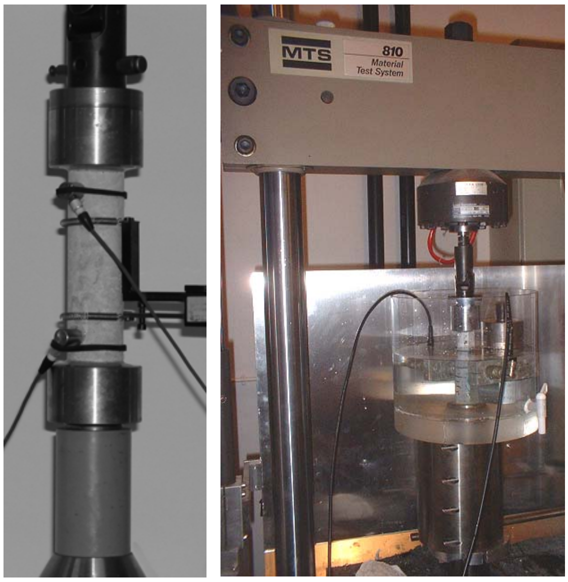
In order to study the history damage of mortar cylinder 120mm in length under tensile test, all tests were performed by using an experimental set-up shown inFigure 1a. The uniaxial tensile tests were conducted using a servohydraulic MTS model 810 testing machine equipped with a 100 kN load-cell. The displacement rate used was 2μm/s. Strain gauges with a gauge length of 30mm were used. The axial elongation was measured by using an extensometer with a 12.5mm gauge length.

3.2. Acoustic emission instrumentation:

A two-channel Mistras 2001 data acquisition system of Physical Acoustics Corporation (PAC) with a sampling rate of 8MHz and a 40dB preamplification were used to record AE. The total amplification of the recording system was 80dB. Ambient noise was filtered using a threshold of 26dB. AE measurements were achieved by using two resonant micro-80 PAC sensors which have a resonant frequency around 250kHz. The amplitude distribution covers the range 0–100dB(0 dBcorresponds to 1 μV at the transducer output). The nominal distance between the sensors was 60mm or 100mm. After installation of the transducers, a pencil lead break procedure was used to generate repeatable AE signals for the calibration of each test. So the acquisition parameters have been set as follows: peak definitiontime (PDT)=100 μs, hit definition time (HDT)= 200μs and hit lock time (HLT)= 1000μs. Velocity and attenuation of waves have been measured several times for each kind of specimens. The velocity is required to localize the AE sources from the difference in arrival times between the two sensors (around 3500m/s). It hasn't been observed an evolution of the wave's velocity with the s/c ratio. The relation between the measured peakamplitude and the distance between the pencil break and the sensor shows that the reduction of the peak amplitude is approximately 100dB/m. This value is quite large compared to the attenuation in steel, but is typical in concrete. After the calibration step, AE was continuously monitored during tensile tests. For each captured signal, a procedure of source localization was performed. In order to avoid irrelevant influences, only AE signals from events located between the sensors are processed. Six parameters were calculated for each signal from the waveforms: amplitude, duration, rise time, counts, counts to peak and energy. Furthermore, each waveform was digitized and stored.

3.3 Ultrasound instrumentation:

By means of an ultrasonic method, the evolutions of the speed and the ultrasonic attenuation of the longitudinal waves propagating have been followed in the material studied. The evaluation of the damage in the samples by EA and by Ultrasounds using the method of dumping. The ultrasonic measures and the follow-up by acoustic emission were simultaneously applied to samples of classic mortar and mortar strengthened by fibres of steel, subjected to a request of drive. The purpose is to identify the mechanisms of damage occurring during this test lead until the break.
The test tube, as represented on Figures 1b is used to eliminate the phenomenon of diffraction of the waves due to the cylindrical shape of the sample. This one was manufactured in a way that both ultrasonic transducers were in front of a plane surface (Figure 1b). After rectification of these two faces, the thickness of the sample is 24.45mm. The sample was taken up on the machine with a length of 120mm having cut both extremities.



(a) (b)

Figure 1 *Experental setup for tensile test with acoustic emission and ultrasound instruments*

3.4 Materials and mix proportion:

The cement used was Lafarge Portland cement (HTS 52, 5 PMES). Its chemical composition is given in Table 1. The specimens were prepared with a water-to-cement (w/c) weight ratio equal to 0.50. The aggregates used were standard sand with a maximum grain size of 2mm. The composition of mortar is given in the Table 2. The density of the obtained test tubes is 2240kg/m3. The sand, the cement and the fibers were mixed for 5min. Water is slowly added while the dry materials are being mixed and then the mixture is stirred with water for 10min. After 10min, the mould is vibrated on a table vibrator. Mortar cylinders of 120mm length and 30mm diameter were produced.
Characteristic of steel fibres:length/diameter ratio in the order of 81, the length of which is 13mm, and the diameter is 0,16mm. On the other hand, their resistance in drive is 2.5GPa. The specimens were covered with plastic to prevent the evaporation and stored in environment laboratory for 2 days. Thereafter the cylinders were demoulded and the

specimens were cured in water at 20°C until the age of 28 days.

Table 1 *Chemical composition of cementused in study*

Constituent	% by Wight	Constituent	% by Wight
CaO	63.8	C_3S	65.5
SiO_2	22.8	C_2S	15.8
Al_2O_3	2.7	C_3A	3.9
Fe_2O_3	1.9	C_4AF	5.9
MgO	0.8	$CaSO_4$	3.7
Na_2O	0.2	CaO libre	1.0
K_2O	0.2		
Mn_2O_3	0.1		
TiO_2	0.1		

Table 1 *Composition of mortarsamples (normalizemortarfrom French standard)*

Sand (g)	Cement (g)	Steel fibres (g)	Water (g)
1500	500	5	250

4. Results and discussion

Figure 2 shows the answer of the mortar sample under tensile load (stress strain curve). It shows a linear behaviour until the failure of the sample.Very small part of non-linearity is observed before the failure.

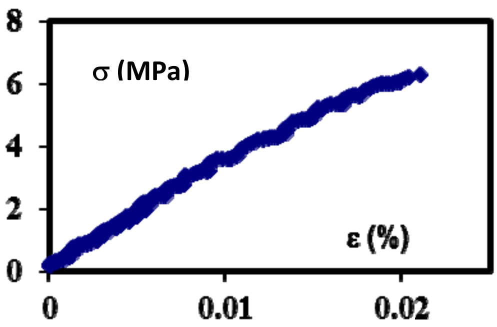


Figure 2 *Stress (strength in MPa) strain (%) answer of mortar during tensile test*

4.1 Ultrasound measures:

The experimentalsignals are shown in Figure 3. The left signal is the signal acquired in the water in absence of the sample, and the right signal is the signal acquired for the mortar sample.

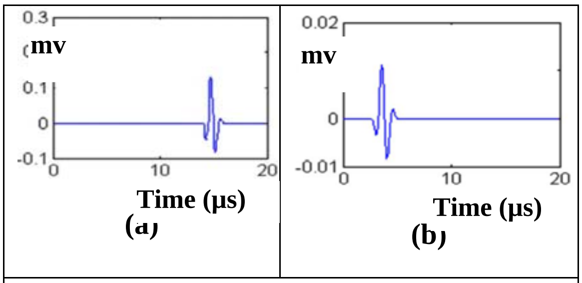


Figure 3 *The signal in the water (a) and the signal in the presence of the sample (b)*

The sample thickness is 24.45mm, its density is 2240kg/m^3, and the speed of propagation of the longitudinal waves in the water 1478m/s. The desperation of the speed and the attenuation on one mortar sample are shown in Figure 4, by using transducers of 1MHz. These curves allow reaching the values of speeds and the attenuation for a range of frequency. It shows a range from 1.2 to 2MHz. For a given frequency, we find the corresponding speed and the mitigation. For example, with the frequency of 1.5MHz, we reach the speed V = 4544m/s and in the mitigation equal 8.1dB/cm.

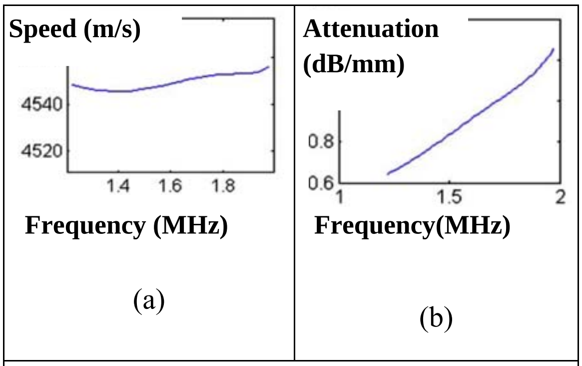


Figure 4 *Evaluation of speed (a) and the attenuation (b) as a function of frequency*

4.2 Influence of the hydration of mortar on ultrasound measures:

The mortar is a material very sensitive to the absorption of the water. This phenomenon of absorption perturbs the measures of the speed and the attenuation of ultra-sound waves when the measure is the dumping.

To examine this effect, we immersed the sample in the water, and we drew the evolution of the two parameters according to the time of dumping, as shown in Figures5 and 6. The values of speed and mitigation are calculated for a frequency of 0.87MHz.

These curves show that the water has a big influence on the moderate values of speed and attenuation, in particular when the sample has just been placed on the device of measure. It is thus necessary to take into account this effect to eliminate the errors.

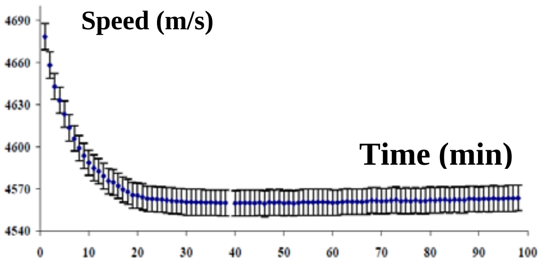


Figure 5 *Effect of the absorption of the water on the speed*

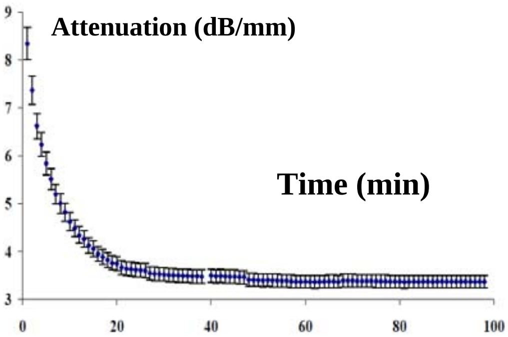


Figure 6 *Effect of the absorption of the water on the attenuation*

4.3 Results concern the mortar:

The same trial chap was made on mortar strengthened by fibres of steel. The evolution of the attenuation during the tensile test is shown in Figure 7. The attenuation (red)is increased with the increasing of strength (black) on the samples until failure. It is also notice that the order of magnitude of the values of attenuation is more important for the mortar, where the evolution is more than 5.59dB/cm for the first measure and ends by the value of 6.12dB/cm for the last measure of attenuation.

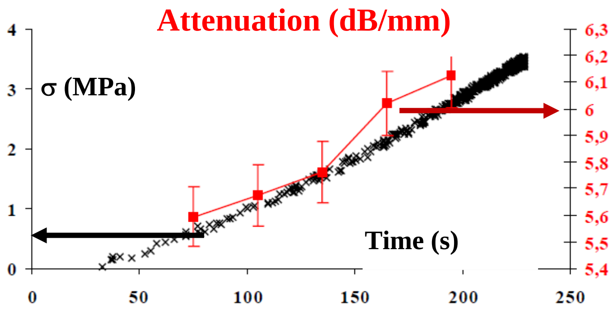


Figure 7 *Evaluation of the attenuation (red) as a function of time and strength (black)*

On the other hand, Figure8 shows the evaluation of the speed during the tensile test. The speed remains almost constant (equal in 4569m/s). The speed decreases with the increasing of strength on the samples until failure.

The speed presents a relatively significant variation during the test. Indeed, it decreases when the strength increases, whereas it is quasi-stable for the un-strengthened samples.

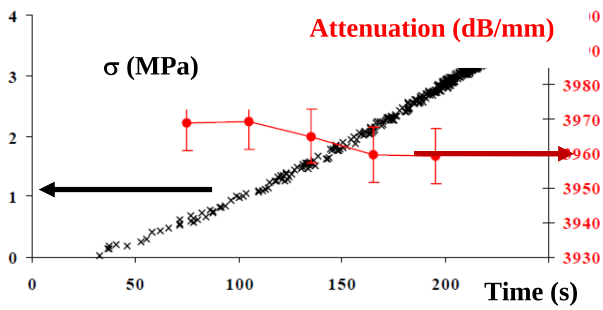


Figure 8 *Evaluation of the speed (red) as a function of time and strength (black) for mortar.*

The correlation between the ultrasound and the acoustic emission detection of damage in moratr sample is given in the Figure 9. Three stages can be obsrved, stage I, II and III. Stage I presents a satble variation on attenuation and the energy created by the insiation of microcrack within this stage. The damage occure in stage II where the attenution of wave increase as the damage increase which is in correlation with the increase of the energy. Stage III represents the final stage where the filluar occure in the samples, where the energy of crack increse dramitcaly until the fillair of the sample.

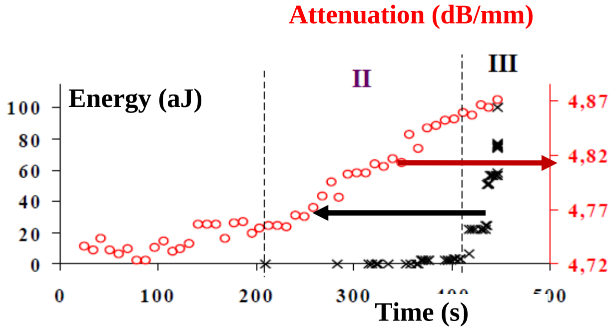


Figure 9 *Identification of the levels of damage by the acoustic emission accumulated energy (black): correlation with the variation of the ultrasonic attenuation (red) as a function of time.*

The correlation between the acoustic emission activity and the ultrasound measurement on the sample is given in the Figure 10. Three stages, I, II and III are observed where, the number of events is increases as the damage occurs in the sample.

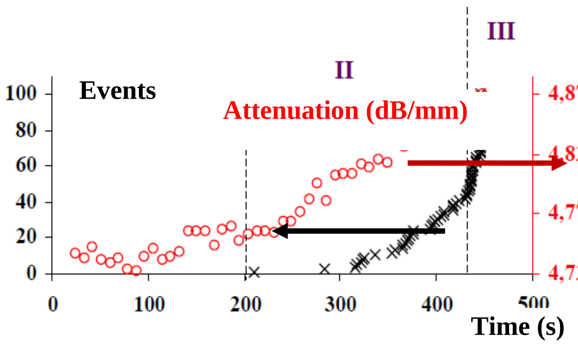


Figure 10 *Identification of the levels of damage by the acoustic emission (accumulated events (black): correlation with the variation of the ultrasonic attenuation (red) as a function of time*

4.4Analysesof results of acoustic mission and the correlation with ultrasound measurement

During the test, the distribution of the activity of the acoustic emission can be divided into three stages: stages I, II, and III. In the first stage, there is no acoustic activity. This stage corresponds to the zone A, as shown in Figure9 and 10, when the strength and the ultrasonic attenuation remain almost stable during the time of load.

In the stage II, the acoustic activity begins weakly, and then it increases according to the increase of the strength. The acoustic activity in this stage is correlated in a significant increase of the attenuation. The acoustic emission becomes important in stage III when, the nit accelerate until the failure of the sample. This result is observed in both ultrasound and acoustic emission.

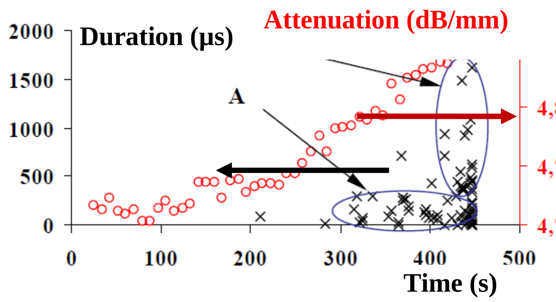


Figure 11 *Duration of the acoustic emission correlated in the evolution of the ultrasonic attenuation*

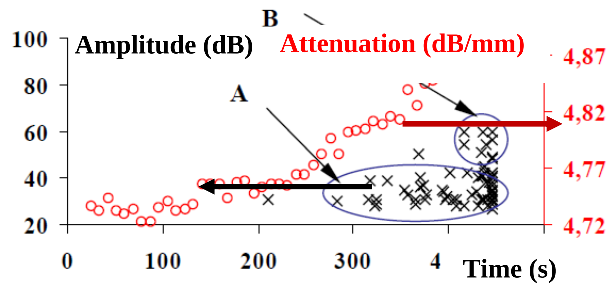


Figure 12 *Amplitude of the acoustic emission correlated in the evolution of the ultrasonic attenuation*

By means of the ultrasonic method, it is found that the attenuation increases when the load increases. The slope of this tendency is observed until the failure, represented by the zone (B) of the Figures 11 and 12. By the data analysis of acoustic emission, this zone can be divide into two stages of behaviour: stage II and stage III, are shown in Figures 9 and 10. This behaviour detected by both methods in association with the damage in the material. Two types of the salvoes of acoustic emission were found: salvoes A and salvoes B, represent in Figures11 and 12. These two populations of salvoes are characterized by their amplitudes and their durations of the signals of acoustic emission.

According to a microscopic study made by Elaqra [7], the mechanism of damage is divided into two stages: at first, the creation of microcracks on the borders and the interface of the defects and the pre-existent pores within the material. This Stage corresponds to the emission of the salvoes of type A. Then the development and the coalescence of these microcracks, leading to the break of material; this stage corresponds to the emission of the salvoes of type B.

For this material, the existence of three phases is observed. The first one in which the strength is very low or almost not exist. In this zone, there is no evolution, neither ultrasonic nor by acoustic emission. As soon as the strength begins to apply both methods show themselves at the same time as the material is under strength. The value of the attenuation increases according to the increase in the value of the applied strength. This value depends very strongly on the applied strength: the more the strength, the more the attenuation is important. The value of the attenuation in the case without load is very different from that observed just before the break. The evolution of the ultrasonic speedwas a very low in the un-strengthened mortar.

As for the acoustic emission, at first low and occasional at the beginning of the application of the strength, this domain being characterized by long-term signals and low amplitude; It becomes energy and intense under higher strength. In the failure, this emission becomes very intense and very energy.

Via the method of the ultrasounds, it is notice that the value of the attenuation is a good characteristic to gauge the health of this material. Via the method of acoustic emission, we notice that the distribution and the intensities of the signals of acoustic emission hanging the load are very good indicators of the health of this material.

5. Conclusion:

A non-destructive global approach has been tried for the characterization of the damage of the mortar, which combines the ultrasonic evaluation and the acoustic emission.

So, during an ultrasonic test of drive, the speed and the attenuation were measured on a mortar test tube. Simultaneously the acoustic emission was collected.

Very net correlations between the fall of the ultrasonic speed, the increase of the attenuation and important acoustic activity were observed. This approach allowed distinguishing the various mechanisms of damage. It showed a very good correlation between the loss of rigidity (in the macroscopic scale), the acoustic emission and the witness of the damage in the microscopic scale. We thus saw that an approach

6. Further studies:

This work open for another studies concerning the classification of each salve of acoustic emission and ultrasound. Events from interfacial transition zone, cracks from porosities and propagation of crack before failure must be studied in next step.

Acknowledgement

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References:

[1] Goszczyńska, B. Analysis of the process of crack initiation and evolution in concrete with acoustic emission testing. *Archives of Civil and Mechanical Engineering*, ***14(1)***, (2014) 134-143.

[2] Hu, J. L., and Feipeng, X. Evaluation of concrete fracture procedure based on acoustic emission parameters. *Construction and Building Materials*, Vol. ***47***, (2013) 1249-1256.

[3] Elfergani, H. A., Pullin, R., and Holford, K. M. Damage assessment of corrosion in prestressed concrete by acoustic emission. *Construction and Building Materials*, Vol. ***40***, (2013) 925-933.

[4] Qingli, D., Kenny, N., Jun, Z., et al. Damage investigation of single-edge notched beam tests with normal strength concrete and ultra-high performance concrete specimens using acoustic emission techniques. *Construction and Building Materials*, Vol. ***31***, (2012) 231-242.

[5] Tetsuya, S., Hidehiko, O., Ryuichi, T., et al. Use of acoustic emission and X-ray computed tomography for damage evaluation of freeze-thawed concrete. *Construction and Building Materials*, ***24(12)***, (2010) 2347-2352.

[6] Shah, A. A., and Ribakov, Y. Effectiveness of nonlinear ultrasonic and acoustic emission evaluation of concrete with distributed damages. *Materials & Design*, ***31(8)***, (2010) 3777-3784.

[7] Elaqra, H. *Study of damage and reinforcement of composite on cimentitous materials*, PhD thesis, INSA de Lyon, France (2004)