Correlation between acoustic emission parameters and fracture behavior of repaired marble specimens

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Introduction

Acoustic emission has been used for the monitoring of cement-based materials like concrete and mortars, but also metals, rocks, **marbles, and granites** covering all the commonly used materials that are included in structural elements at the constructions

The basic principle of the AE is the record of the elastic pulses after crack initiation and propagation incidents with the usage of piezoelectric sensors

In the present study we wish to study the effect during the early stages of loading in three-point bending of repaired marble specimens

Introduction

The damaged specimens were repaired using a suitable epoxy agent then they were mechanically loaded again

The average frequency and RA value showed a satisfactory characterization of the capacity of the material even during early loading. It was an initial effort to correlate low load AE (approximately one-third of the ultimate load) to the final maximum load of marble strength both in the intact and the repaired state

The RA values of repaired specimens during the different stages of loading characterize the bonding failure between the fracture surface and the epoxy resin used for the repair of the specimens.

Experimental part

Materials:

- Two types of marble were used, with an average measured density of 2280 kg/m^3 named California Honey from Morocco and of 2508 kg/m^3 named Crema Mocha from Spain respectfully
- California Honey will be addressed as **MA**
- Crema Mocha will be addressed as **MB**

Experimental part (3-P bending)

BS EN EN 13892-2:2002

Displacement rate 50N/s automatically terminated at the moment of the instant load drop

Two piezoelectric sensors named (R15, Mistras)/ 150 kHz

Specimens:

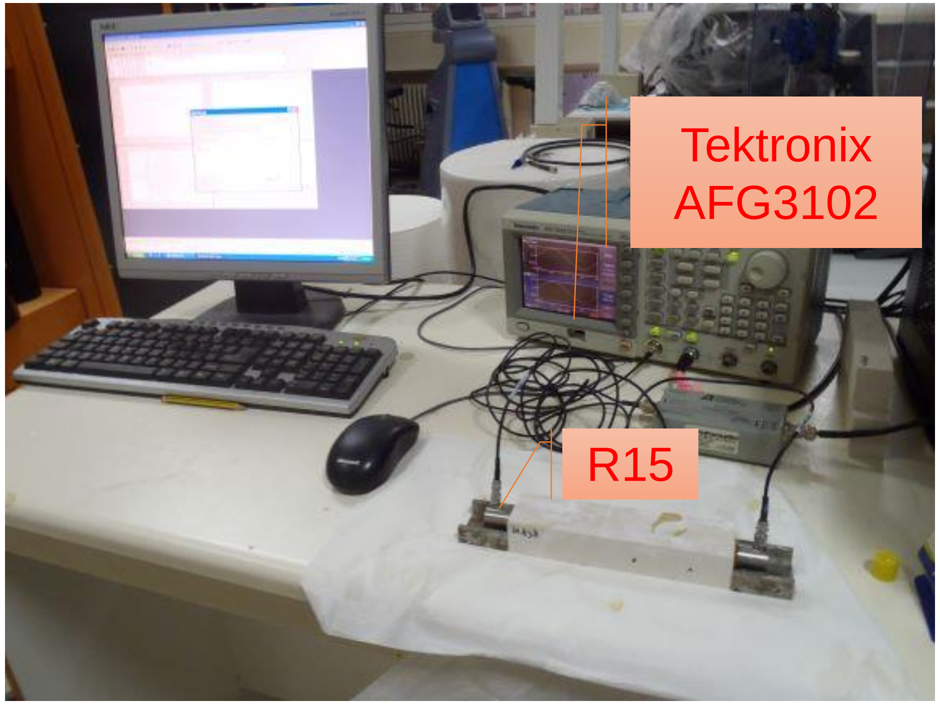
- Twenty-five specimens of both types of marble were tested in this study

Experimental part (Repair)

Repair method:

- Two-component solvent-free bonding system based on epoxy resin and hardener named "Epoxol" in its commercial product name
- The bonding was established with precautions so that the original geometry of the specimen was not altered

Experimental part (Ultrasonic Inspection)

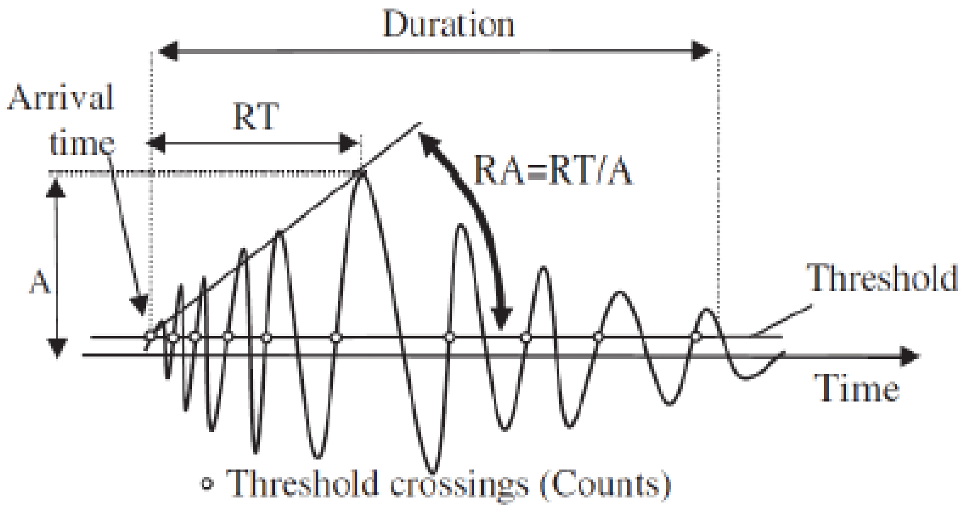


Ultrasonic set up:

- The distance between the pulser and the receiver was of 160 mm and also a layer of grease between the sensors and the specimen placed improved the acoustic coupling
- A waveform generator named Tektronix AFG3102, concurrently with a two-channel PCI-2 Mistras board data acquisition system, was applied
- The resonance of the transducers was of 150 kHz and (R15, Mistras Group).

Experimental part (Acoustic Emission)

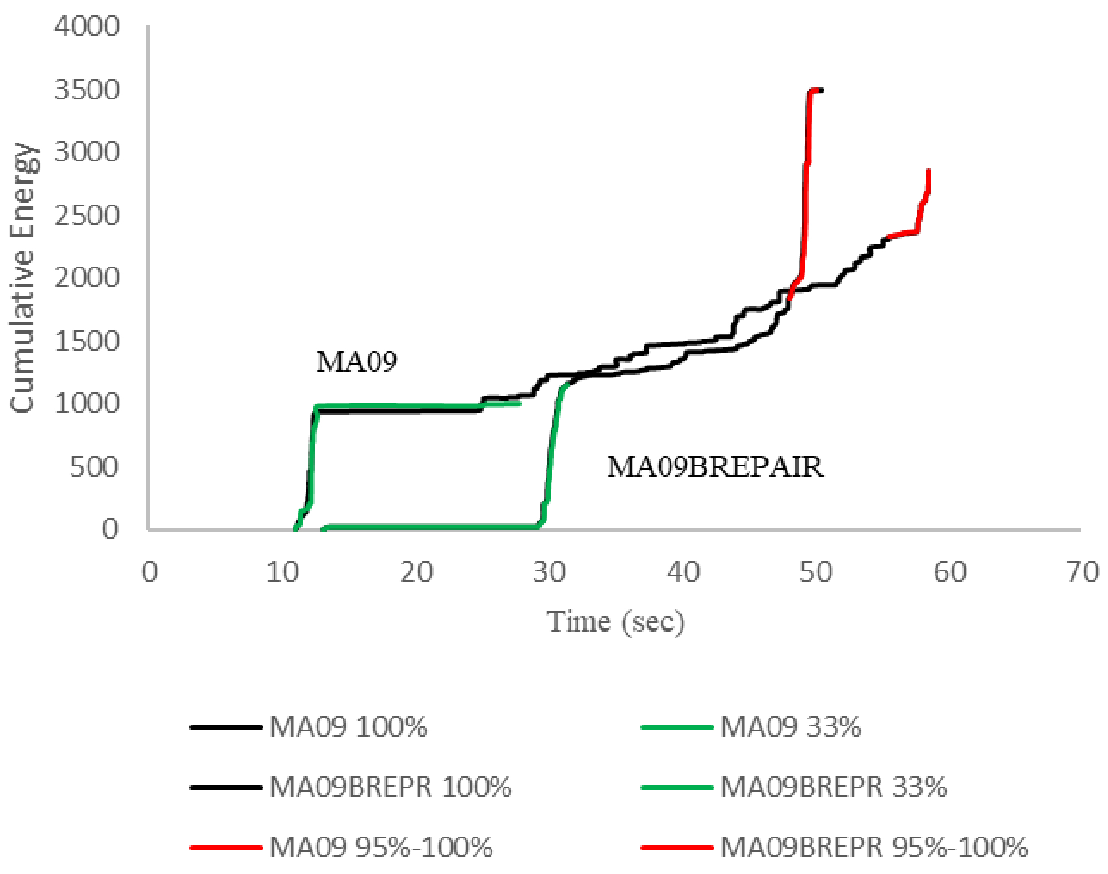
A schematic representation of a waveform



Main features

- the duration DUR (the period between the first and the last threshold crossing),
- the maximum amplitude AMP (dB).
- the "rise time" (RT) (which is the time between the first threshold crossing and the point of peak amplitude in μs). Rise Time is related to the fracture mode of the crack, and so is the inverse of the slope of the initial part of the signal (RA value, RT/A in μs/V).
- AF (average frequency) can be measured by the total number of threshold crossings divided by the duration and can characterize the Frequency content

Results



Cumulative Energy at the three Different stages of loading for same **sound** and **repaired** specimen

- The sound specimens exhibit a large AE rate from very early loading in contrast to the repaired that start emitting after the load reached approximately 25% of the maximum
- This is attributed to the initial elastic deformation of the epoxy which has a lower elasticity than marble

Results (3P bending)

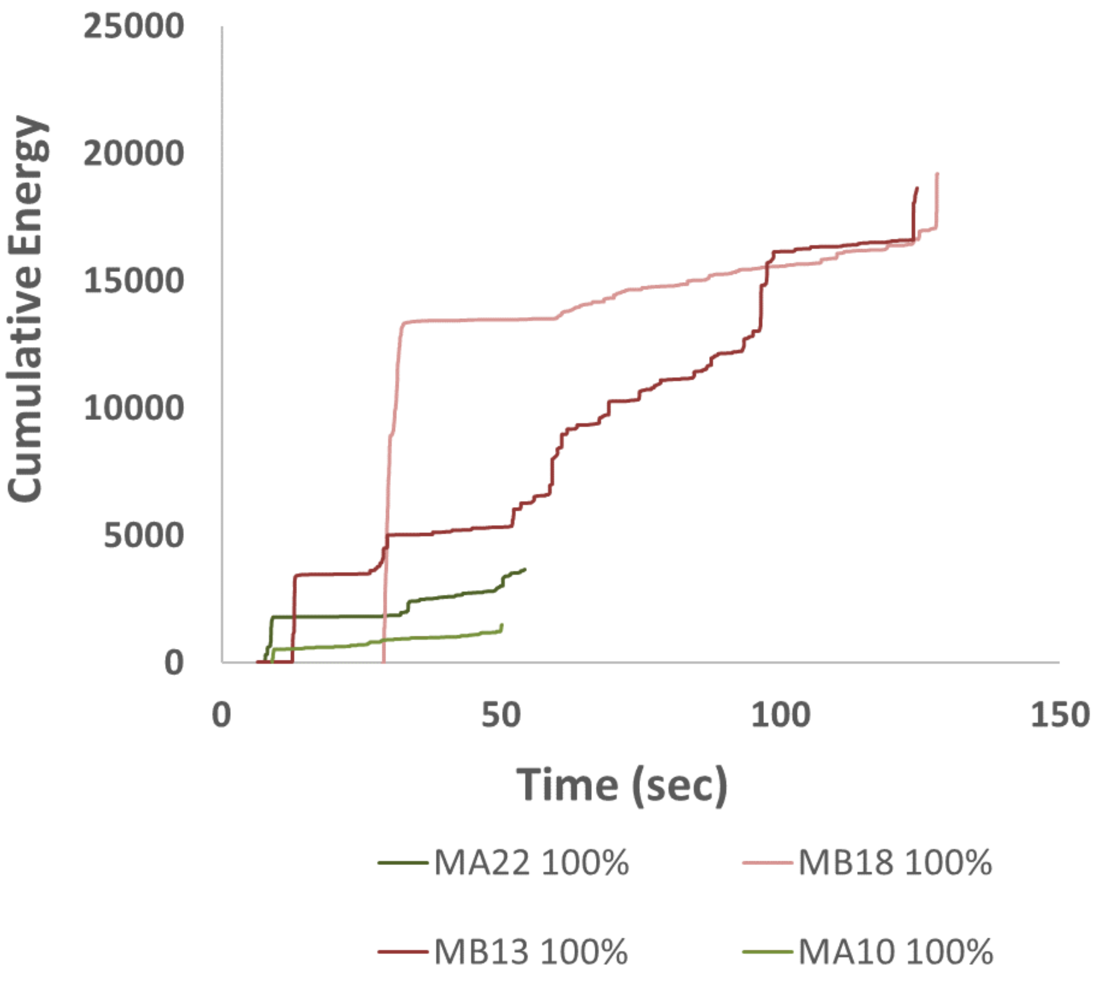
Type A marble has a strength restoration of 0.71; in contrast, type B has only 0.48

Results of the mean values of bending test and AE parameters of two types of marbles sound and repaired during three loading stages

SPECIMEN	Max Load (kN)	CP (m/sec)	Cum ENERG	ENER	AF (kHz)	RA (μs/V)
MA 100%	2,30	4792,98	**3205,42**	8,74	29,32	12848,07
MA 0%-33%			1395,16	11,53	26,95	18170,36
MA 95%-100%			376,58	9,31	30,92	15860,70
MB 100%	5,07	6385,00	**4422,90**	10,37	38,89	9153,67
MB 0%-33%			1474,93	9,03	37,25	8079,21
MB 95%-100%			1520,00	23,13	39,36	20710,67
MA Rep100%	1,65	4792,98	**4391,63**	9,57	40,46	**6815,34**
MA Rep 0%-33%			1160,89	7,30	39,78	6445,82
MA Rep 95%- 100%			2539,79	15,17	38,30	**9569,33**
MB Rep 100%	2,45	6385,00	**2745,86**	11,21	41,26	**6633,87**
MB Rep 0%-33%			764,69	7,89	39,58	4890,31
MB Rep 95%-100%			1573,14	15,52	44,06	**9179,65**

The level of recovery in the fracture surface is mostly responsible for the final failure mechanism because the epoxy resin has a significant and dominant role for the bond that occurred at the surface microstructure

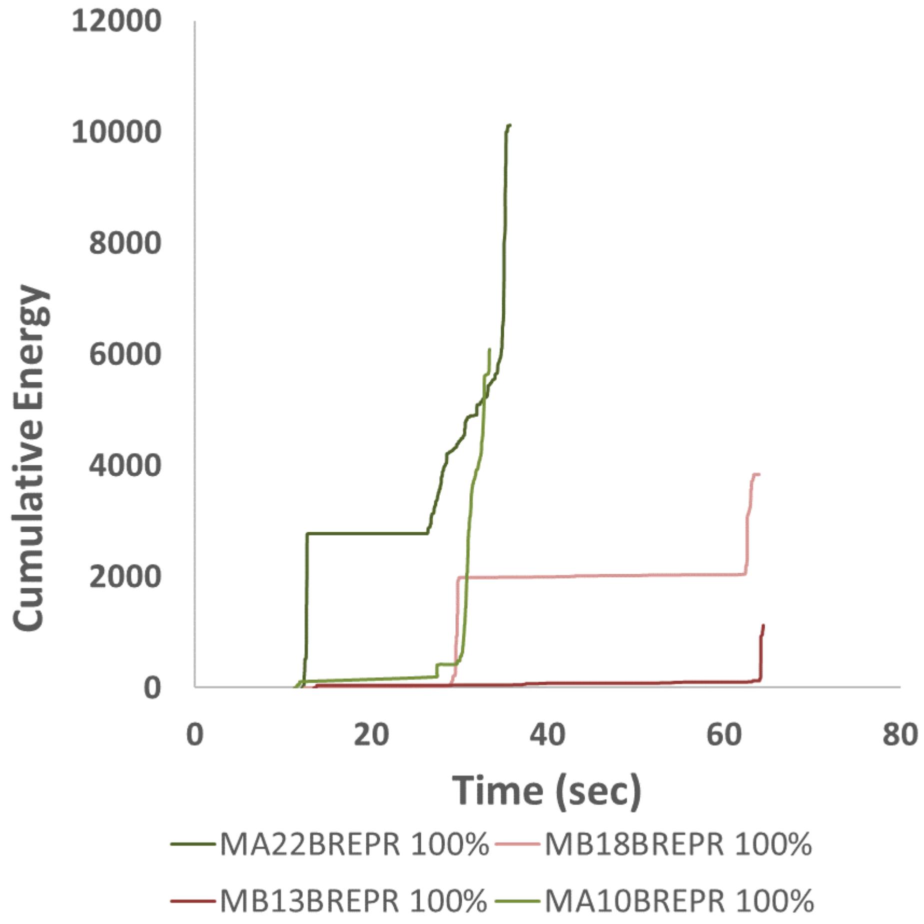
Results



Sound Specimens

Type MB that also achieves and higher maximum strength shows higher Cumulative Acoustic Energy

Results



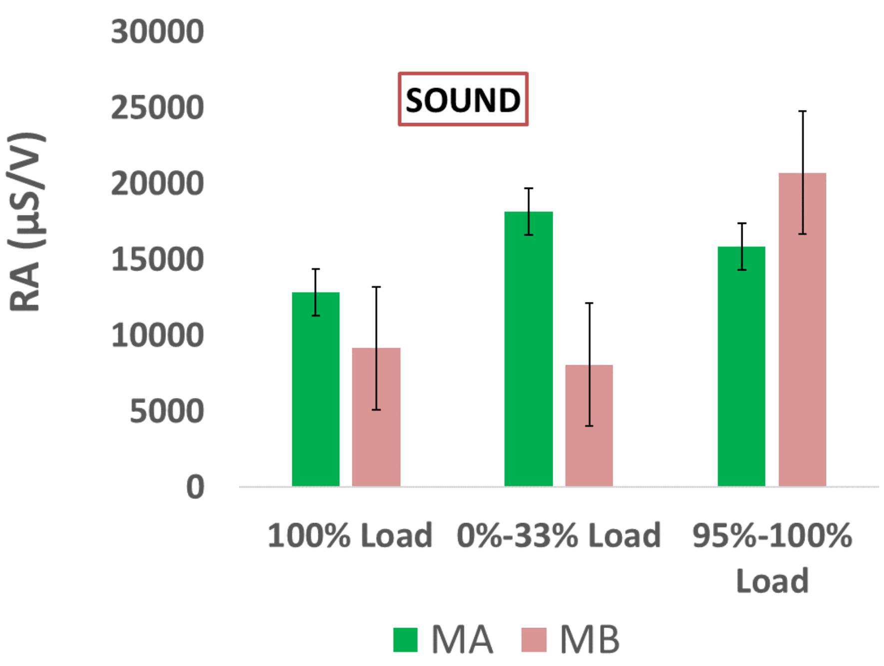
Repaired Specimens

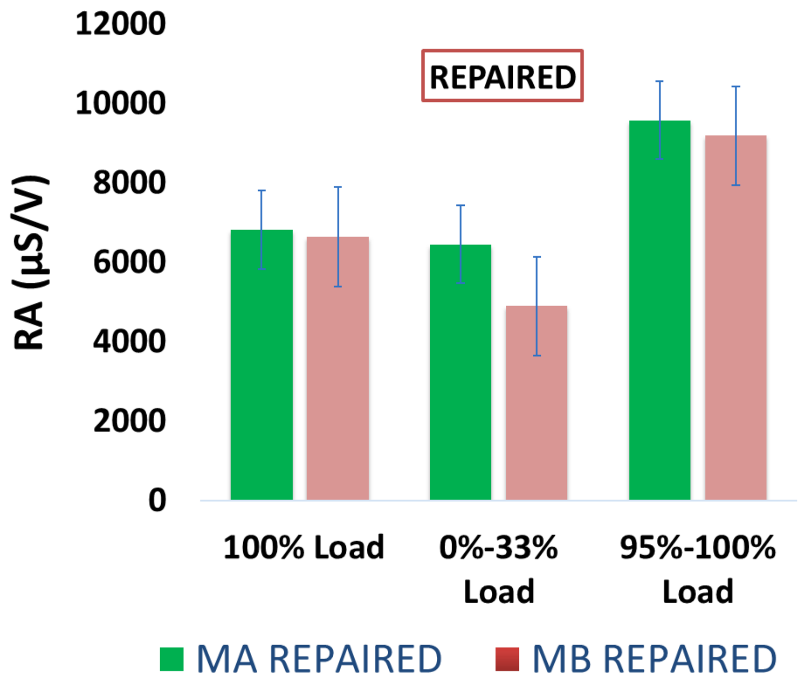
Type MA shows higher Cumulative Acoustic Energy even though it exhibits lower maximum strength than Type B (but demonstrates a much better restoration level)

For the acoustic emission energy emitted, the most significant role is on the **interface bonding between the epoxy and the marble at the fracture surface** because the level of restoration seems to correlate with the cumulative Energy

Results (3P bending)

Mean values of RA of MA and MB sound and repaired specimens for three loading stages

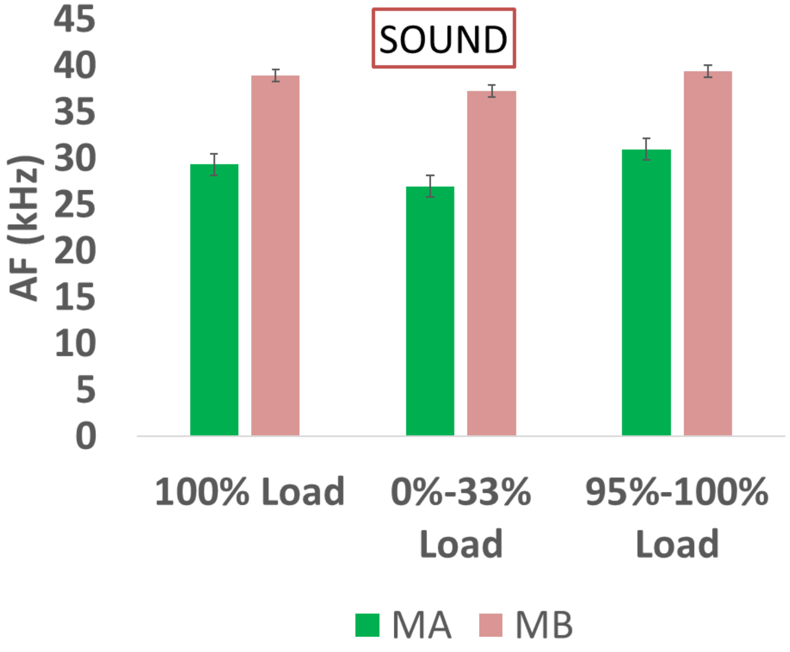


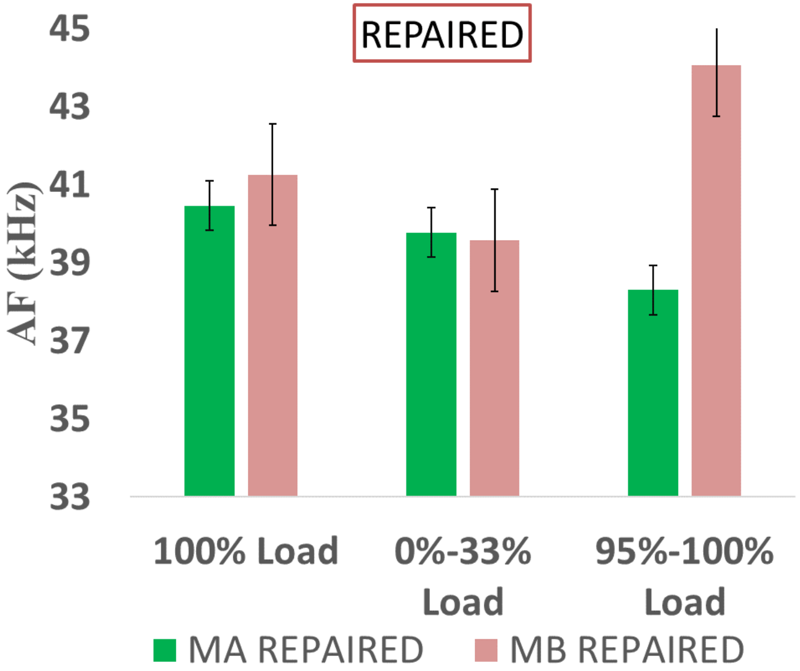


At the last stage close to macroscopic fracture, the values are much closer with MB showing even higher values. The trend is that parameters affected by the mode of fracture get closer to equal values at the last stage of loading close to the macroscopic failure. It is proved more clearly by the repaired specimens

Results (3P bending)

Mean values of AF of MA and MB sound and repaired specimens for three loading stages





Average Frequency AF, do not show very clear results regarding the characterization of the fracture mechanism for the repaired samples

- The main reason is the resonance of the R15 sensors, which prevent the AF from successfully describes the failure process even with the more detailed examination through the different loading steps analysis

Conclusions

While the level of restoration of Marble Type A is prominently 0.72 compared with the 0.48 of marble Type B the average cumulative Energy per specimen for the cluster of all the hits, follows the trend of restoration for the repaired sample

- The Cumulative energy of repaired Marble Type A not only increased after repair but also overpassed the cumulative Energy of repaired Marble Type B.
- For the acoustic emission energy emitted, the most significant role is on the interface bonding between the epoxy and the marble at the fracture surface consequently the level of restoration seems to correlate with the cumulative Energy.

Conclusions

While the RA values of sound specimens of Type A are higher about 40% compared with the Type B accordingly, the restored ones have shown different trend reaching equal values amongst the two types for the 100% population of hits examined. The explanation can be found of the dominant role of the epoxy bonding interface with the marble that affects the mode of fracture in both Types of Marble with the same mechanism even with not the same effectiveness.

At the final (95%-100%) loading stage, the RA gets almost equal values for both repaired Marble Types. Justification is that RA affected by the mode of fracture and getting closer to equal values at the last stage of loading before the macroscopic failure. At that point, the stress field is dynamic with a high dosage of randomness after each crack propagation event compared to the initial static field.

Thank you

Any questions?

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