Damage Characterisation and Structural Health Monitoring by Means of Nonlinear Acoustics

M. Bentahar, R. El Guerjouma, T. Monnier, L. Deville and J.C Baboux

INSA de Lyon , GEMPPM UMR CNRS 5510, 20 Avenue A. Einstein- Bât B. Pascal – 69621, Villeurbanne, France

Email: mourad.bentahar@insa-lyon.fr

Introduction

Linear acoustical methods are mainly based on the measurements of the ultrasonic waves velocities and/or attenuation. Generally these methods are not capable to detect small changes due to damage especially when it is about characterising heterogeneous materials. To overcome this difficulty, other methods known to be « nonlinear » have been used and seem to be sensitive to small changes even for weak excitation levels [1,2]. In this study we have been interested by a nonlinear method based on the change of the resonance frequency of a given vibrating mode with respect to the excitation level. Indeed, when a material is damaged its modulus decreases creating thus a relationship between its vibratory behaviour and the used excitation level. This behaviour has been used to characterise a polymer based composite (Shield Moulding Compound SMC) and a civil engineering concrete.

Experimental device

The experimental devices used for the materials characterisation is presented in Figure 1. The gain-phase analyser emits sine waves while sweeping in frequency exciting the materials eigenmodes. The signal is then amplified at a constant gain and the excitation level could be changed on the analyser. For composite plates, we have stuck two piezoelectric transducers on its both extremities to emit and receive the ultrasonic vibrations. Being cylindrical in shape, the concrete has been excited on one face with a piezoelectric transducer while the reception was made with a laser vibrometre. Signals are then displayed by the analyser and transmitted to the microcomputer.

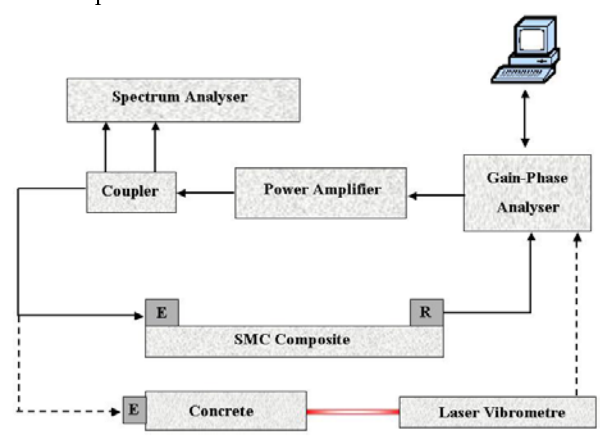

Figure 1: The experimental device used to characterise composites as well as concrete

Experimental results

Composite samples were damaged with three points bending tests to obtain a localised and progressive damage on the same sample while concrete samples were submitted to compression tests. On Figure 2, we can see the resonance curves obtained for the SMC composite at the intact and damaged states (variations are the same for the concrete). These curves show clearly the change in the relationship existing between the frequency and the excitation level. This particularity typical of nonlinear oscillators is an important damage indicator as it happens at early damage states for weak strains ~10^{-7} [2,3,4].

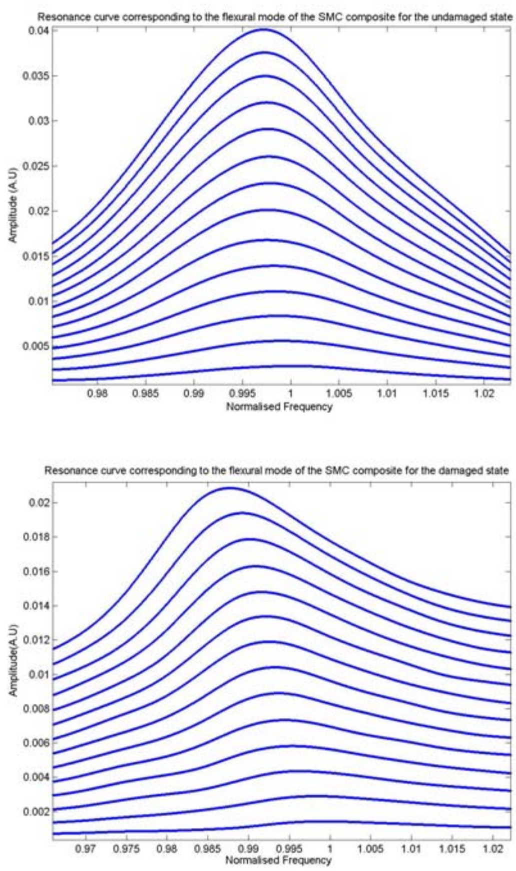

Figure 2: Resonance curves of the SMC composite before and after damage respectively (the normalisation is made in relation to the flexural mode)

Slow dynamics

Many works have studied the influence of a strong excitation on the elastic modulus of materials after a conditioning of few minutes [3,5,6]. Being inspired by these results we have applied this principle on composites and concrete before and after damaging. The conditioning time was of 13 minutes during which we have swept around the Young's mode for concrete and the flexural mode for SMC composite. Contrary to the damaged states, we did not notice any changes in the resonance curves during the conditioning for the intact states. Indeed, when materials are damaged, their modulus decreases continuously during the conditioning provoking a decrease in the vibrations amplitudes as well as resonance frequencies. The latter seem to change as the logarithm of time as seen in Figure 3. The conditioning effect could be seen otherwise. If we apply a strong excitation and sweep upward in frequency until we reach the maximum amplitude and at this point we inverse the sweeping direction, we notice a hysteresis loop that did not exist in the intact state. Figure 4 shows the hysteresis loop, which is a sign of a partial accumulation of energy by the material in the damaged state.

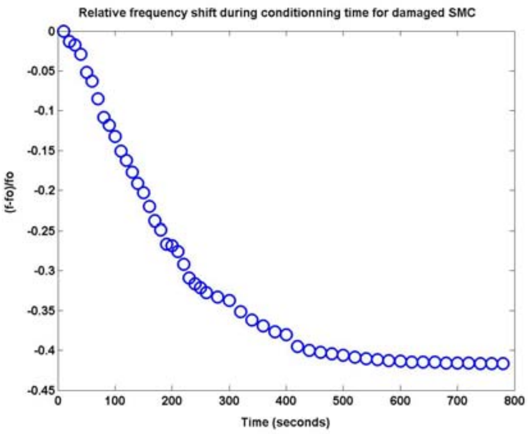

Figure 3: The logarithm change of the resonance frequency with time during the conditioning

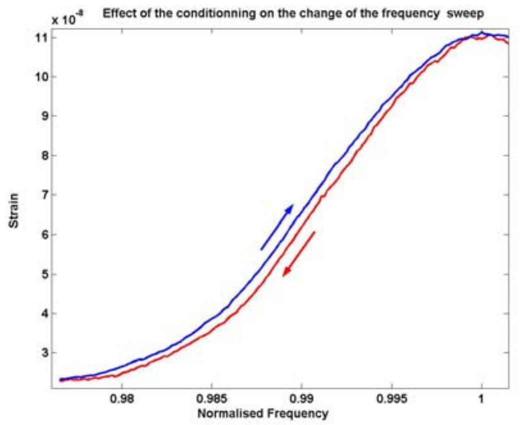

Figure 4: Appearance of hysteresis loop as another consequence of the conditioning in the case of concrete

After the conditioning, we unplug the amplifier and let the material relax. The relaxation is followed with frequency sweepings of a weak level. This time the frequency increases as the logarithm of time as shown in Figure 5. These results found for concrete and composite seem to be in accordance with those found for other materials like rocks and this despite the differences in their chemical compositions and microstructures [2,6].

During these experiments we have noticed a dependence of the conditioning as well as the relaxation times on the materials states. In particular, the way the material relaxes depends on the conditioning level and time. It depends also on the material's health, in other words on its ability to accumulate energy during the conditioning. So we have applied a fixed excitation level for 5 minutes to condition the SMC at its different damage states. This has given the promising result shown in Figure 6. The sensitivity of the relaxation time to the material's health makes it a good damage indicator despite the absence of a quantification of damage, but other fields are being explored to overcome this.

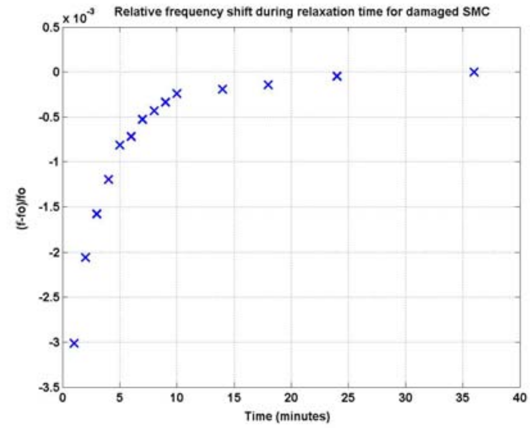

Figure 5: The logarithm change of the resonance frequency with time during the relaxation

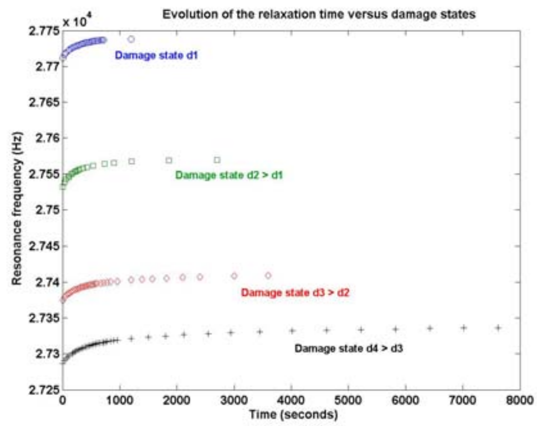

Figure 6: Evolution of the relaxation time for different damage states in the case of SMC

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