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Mechanical Resonance Spectra of Composites and their Components: Hard in Soft Materials

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Abstract. The resonant ultrasound spectroscopy (RUS) is a non-destructive characterization or assessment technique based upon the measurement of the mechanical resonant spectra of the samples [1]. In this work, RUS measurements have been performed upon composite samples consisting of a hard material embedded in a softer medium, as well as upon their separate components. The hard components used have been galvanized steel rods of 1 mm diameter and lengths of 15 and 27 mm. The softer medium was a seedless green grape of 29 mm length and 18 mm width. The two composite samples considered have been obtained by insertion into the grape of one rod at a time. The measured spectra have been compared and the feasibility of recognition of the spectra of the separate components from the composite spectrum is discussed.

Keywords: resonant ultrasound spectroscopy, composites, spectra recognition.

1 Introduction

Resonant Ultrasound Spectroscopy (RUS) is a means of determining material properties of an elastic object by exciting the resonant frequencies (normal modes) of the object. The spectrum of modes of an elastic object contains much information about the object, both microscopic and macroscopic. The information that can be derived from such a spectrum includes information about the object's geometry and density. In principle, all this information can be acquired from a single, accurate measurement of an object's resonant spectrum, in a non-invasive and non-destructive way [2].

Aim of this work is to study the possibility of extending these useful features of RUS to embedded objects. For this reason, RUS measurements have been performed upon composite samples consisting of a hard material embedded in a softer medium, as well as upon their separate components. Correlation analysis provides some insight into the features.

The feasibility of recognition of the spectra of the separate components from the composite spectrum is discussed. This can be useful to observe an object inside another without being invasive and obtain their individual characterizations without separating

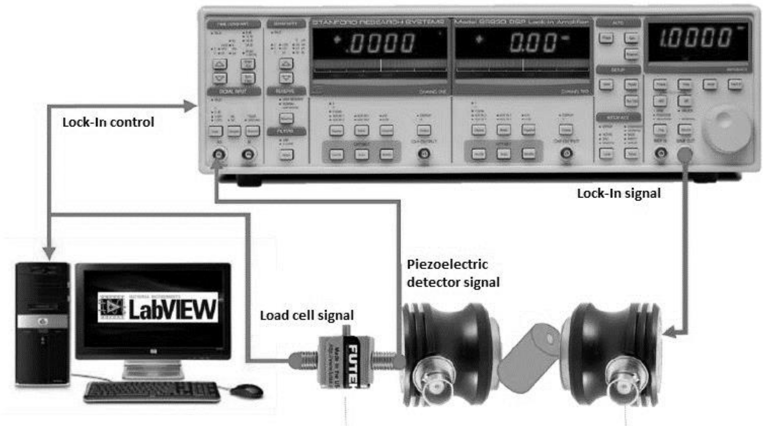

Fig. 1. Frequency-Domain RUS system.

them. With this information in future studies, the object and its state could be recognized only by having its spectra.

2 Methodology

2.1 Measurement Arrangements

The setup for the used frequency-domain RUS system is shown in figure 1. It consists of two piezoelectric shear wave transducers Panametrics V150, a load cell Futek LRM200, a Stanford S830 Lock-In Amplifier (LIA), and a computer to perform the acquisition. The LIA is used both to excite by sinusoidal frequency scan the sample through one of the piezoelectric transducers and to measure the sample's response through the other piezoelectric device. As for the load cell Futek LRM200, it is directly attached to the piezoelectric detector to guarantee measurements repeatability and gauging.

The samples are loosely mounted between both transducers. The initial frequency used is 20 kHz and the final are 60 kHz, this with a sinusoidal excitation signal of 5 V. Then the sample's response, amplitude, and phase are recorded by a LabView program. With this information and using Matlab, the correlation coefficient is calculated.

Matlab gives a correlation coefficient matrix (1):

$$R = \begin{pmatrix} \rho(A,A) & \rho(A,B) \\ \rho(B,A) & \rho(B,B) \end{pmatrix} = \begin{pmatrix} 1 & \rho(A,B) \\ \rho(B,A) & 1 \end{pmatrix}. \tag{1}$$

This matrix is given by the definition of the correlation coefficient of two random variables, which measures its linear dependence. If each variable has N scalar observations, then the Pearson correlation coefficient is defined as (2):

$$\rho(A,B) = \frac{1}{N-1}\sum_{i=1}^{N}\left(\frac{\overline{A_\iota - \mu_A}}{\sigma_A}\right)\left(\frac{\overline{B_\iota - \mu_B}}{\sigma_B}\right), \tag{2}$$

Table 1. Correlation of 27mm soft, 29mm hard and combined.

Total frequency response (20 kHz to 60 kHz)		Central frequency response (30 kHz to 50 kHz)	
Components	Soft 29 mm / Hard 27 mm	Components	Soft 29 mm / Hard 27 mm
Hard 27 mm	R = -0.1303 p = 0.3237	Hard 27 mm	R = -0.3725 p = 0.0005
Soft 29 mm	R = 0.6538 p = 0.0900	Soft 29 mm	R = 0.5832 p = 0.0000

where μ_A and σ_A are the mean and standard deviation of A, respectively, and μ_B and σ_B are the mean and standard deviation of B[3].

2.2 Samples

The samples are two galvanized steel rods of 1 mm diameter and lengths of 15 and 27 mm, these are the hard components. The other sample is a seedless green grape of 29 mm length and 18 mm width, which is the softer medium use to embed the harder one.

3 Results and Discussion

The total frequency response, from 20 kHz to 60 kHz, of the 27 mm hard and 29 mm soft components are shown in Fig. 2. It can be observed that the soft 29 and the combined are similar in the magnitude of their amplitudes, this means that there are more similarities between them than the combined with the hard 27. Even in the shape of the curve. In a specific range from 30 kHz to 50 kHz, the central frequencies (see Fig. 3), this similarities between the spectra can be noticed even more. This shows that there are characteristics of the soft and hard component in the combined, but also in this combination, there is a variation in the amount of individual component dependent on the sample size. The correlations coefficients of these measurements are shown in table 1 and are a quantitative way to show the above.

2.1 Printing Area

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This shows that no correlation is found when the total response is evaluated but in the central region, where the resonance modes are more alike, the correlation exists between the samples.

In this case, the result indicates that the soft material has the biggest correlation with the combined one. This is related to how the sample is constituted where the hard material is embedded in the soft material, giving combined spectra more similar to the soft spectra.

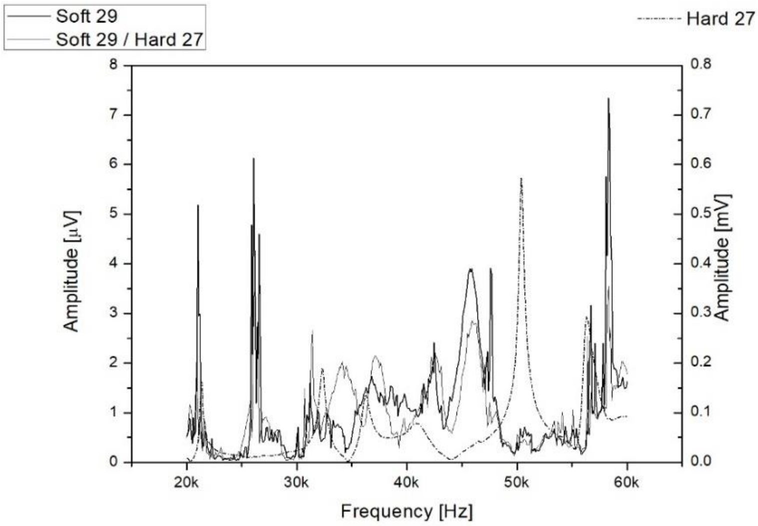

Fig. 2. The total frequency response of 27 mm soft and 29 mm hard.

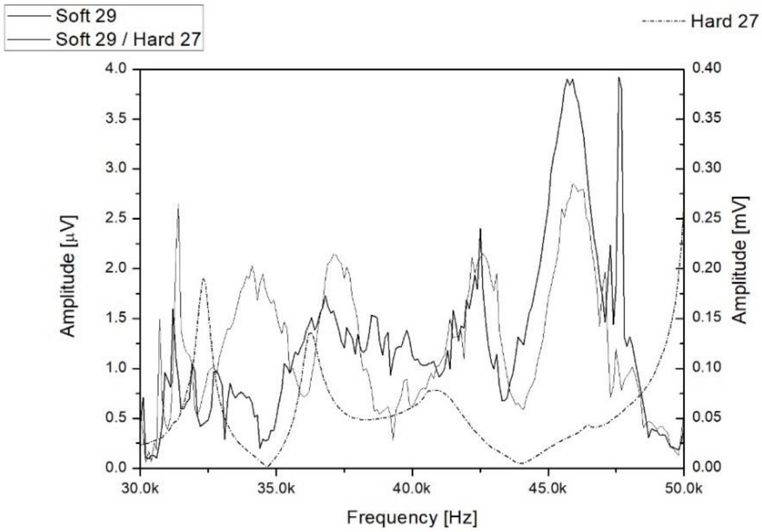

Fig. 3. The central frequency response of 27 mm soft and 29 mm hard.

In the 15 mm hard and 29 mm soft the total frequency response, from 20 kHz to 60 kHz (see Fig. 4) the spectra of soft 29 mm and combined are very similar in shape and amplitude, but if this comparison is made to the combined one with hard 15 mm it may seem like they don't have similarities.

If the final range is observed, from 40 kHz to 60 kHz (see Fig. 5), a similarity between the three spectra is shown, there are some peaks from soft 29 and the combined that coincide in frequency. It is important to clarify that the same range of the previous

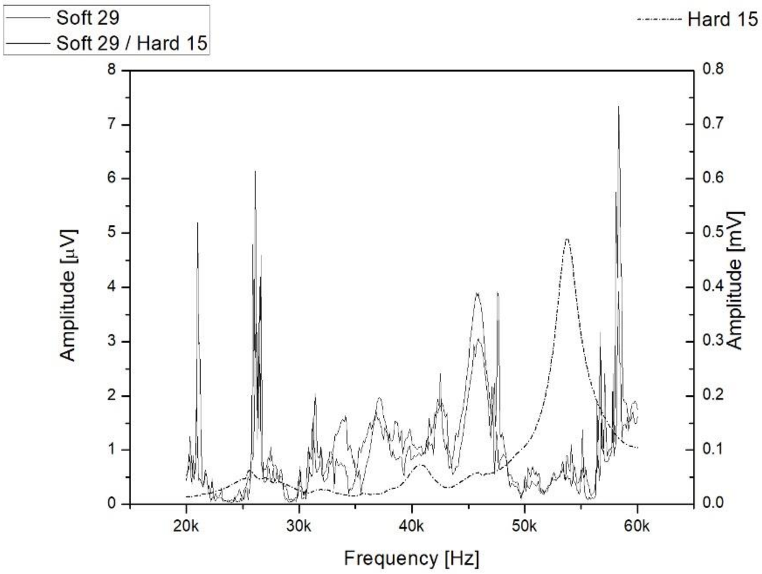

Fig. 4. The total frequency response of 15 mm soft and 27 mm hard.

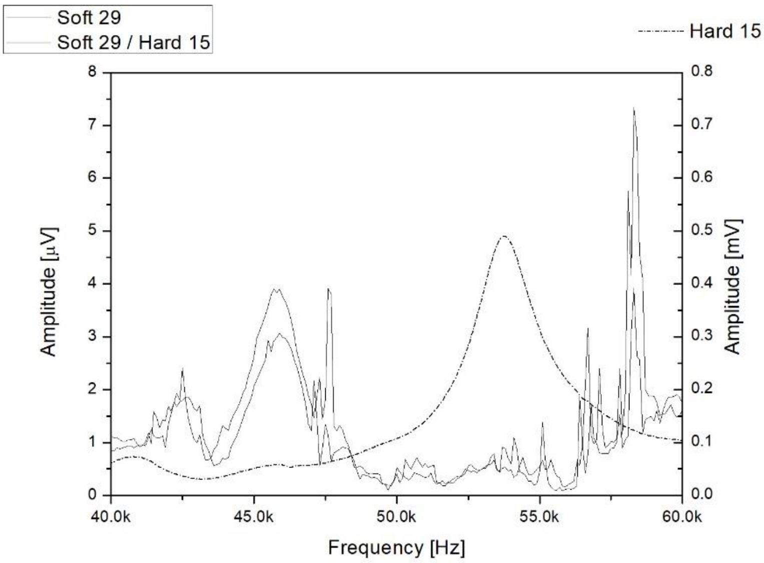

Fig. 5. The final frequency response of hard 15 mm and soft 29 mm.

case (central range from 30 kHz to 50 kHz) is not taken for this correlation because given the dimensions of the hard object the modes are shifted to the right.

There is no correlation between the samples in the total frequency response for 15 mm hard, soft 29 mm and combined one. When the range is taken from 40 kHz to 60 kHz the correlation is favorable; is greater for the soft component because there is even a smaller number of components, compared to the previous case.

Table 2. Correlation of 15mm hard, 29mm soft and combined.

Total frequency response (20 kHz to 60 kHz)		Central frequency response (40 kHz to 60 kHz)	
Components	Soft 29 mm / Hard 15 mm	Components	Soft 29 mm / Hard 15 mm
Hard 15 mm	R = -0.1524 p = 0.0278	Hard 15 mm	R = -0.4119 p = 0.0000
Soft 29 mm	R = 0.7334 p = 0.0022	Soft 29 mm	R = 0.8103 p = 0.0000

4 Conclusion

There is a significative correlation between the combined with individuals' samples, this means that the spectra have parts of both components spectra and it can be observed in qualitative and quantitative ways. Also, this correlation changes for component that it presents: with the small hard sample embedded the correlation between the combined and soft sample is better than with the big hard sample. Moreover, in the other case of having the big hard sample embedded, the correlation between the combined and hard sample is better than with the small hard sample.

References

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