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# IDENTIFICATION OF FREQUENCIES SPECTRUM OF OLD AND NEW VIOLINS USING DYNAMIC ANALYSIS

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***Abstract:*** *The paper presents the experimental investigation on old/heritage and new violins in order to determine the frequencies spectrum, quality factor and damping for each structure. The violins, belonging to a violin school (violin Jacobus Stainer, 1716; violin Johann Georg Leeb, 1742; violin Joseph Klotz, 1747; violin Babos Bela ,1920, Gliga 2020), were subjected to dynamic analysis and the results were presented comparatively. From the point of view of the correlation of the frequency response with the anatomical structure of the wood, it was observed that the symmetry of the face construction mostly affects the values of natural frequencies specific to CBR, B1 +, f5 and f6 modes, that increase with the improvement of face symmetry.*
***Keywords:*** *dynamic analysis, frequencies spectrum, signature mode, old violin*

## 1. INTRODUCTION

Regardless of the field of applicability of the wood, knowing its elastic properties is necessary for the design of the structures where the wood is involved, and also for the predictability of their behavior in time, so that the the material selection could be optimal. Moreover, in stringed musical instruments, the elastic, acoustic and dynamic properties correlated with the anatomical and physical descriptors of wood provide the scientific argument for the acoustic quality of the musical instrument and, last but not least, the economic argument for the price of the finished product. The most important elastic, mechanical, acoustic and dynamic properties of resonant wood that influence the acoustic quality of violins (and, in general, of musical instruments with strings) are: the speed of sound propagation through wood V (m / s), the elastic modulus E (MPa), the transverse shear modulus G (MPa), Poisson's ratio (dimensionless), the dynamic modulus or complex modulus $E_{din}$ or $G_{din}$ (MPa) (according to Spycher, 2008), the specific modulus of elasticity, E'/ ρ (MPa * m / $kg^3$ or $m^2$ / $s^2$), the resonant frequency $f_r$ (Hz), the specific acoustic resistance (impedance) denoted by $R_a$ (after Filipovici, J., 1965) or z (N * s / $m^3$) (Bremaud, 2012), the acoustic radiation K (the acoustic radiation constant - after Ghelmeziu, N., Beldie, I., 1970, Beldeanu, 2008) or R (after Spycher et al. 2008), the quality factor Q and the logarithmic decrement tanδ.

## 2. MATERIALS AND METHODS

Six violins were investigated, five old violins belonging to famous luthiers: a Joseph Klotz violin, Mittenwald (1747), a Jacobus Stainer violin (no label) copy, a Babos Bela violin, Hermanstadt (Sibiu) (1920), a Johann Georg Leeb, violin, Presburg, (1742), an "unbranded", "Fără marcă", violin and a new, current Gliga coded violin, 2020 produced at the S.C. Gliga Musical Instruments S.A. Reghin (Figure 1).
The test method used in this research consisted of dynamic analysis to determine the frequency response of old violins compared to new violins, using two types of structural excitation: the first variant was to hit the body of the violin with the impact hammer (Figure 2, a), and the second, the excitation of the Pizzicato style structure (Figure 2, b). In this study are presented the first test method, in case which, the strings are being locked with an elastic element in order not to influence the response of the sounding board.


**Figure 1:** The analyzed violins

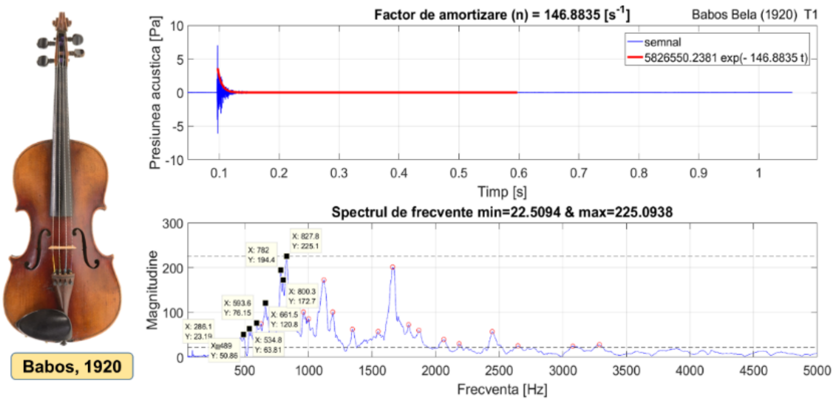
The recording of the acoustic signal was done through a microphone located near the acoustic holes. The signal was collected using a DAQ-NI USB-9233 acquisition board, and the time and frequency analysis was performed with a program developed in MATLAB. For each violin, three signals were collected. The acquired signals were processed, obtaining the values of the natural frequencies the damping factor of the tested violins. The frequency spectrum, the dominant frequency value and the damping factor differ from one violin to another, these results being correlated with the geometric aspects of the violins.


**Figure 2** Testing the violins: a) excitation with the impact hammer; b) excitation of the strings of the violins in Pizzicato style; c) the position of the four strings and the musical note corresponding to the tuned free string

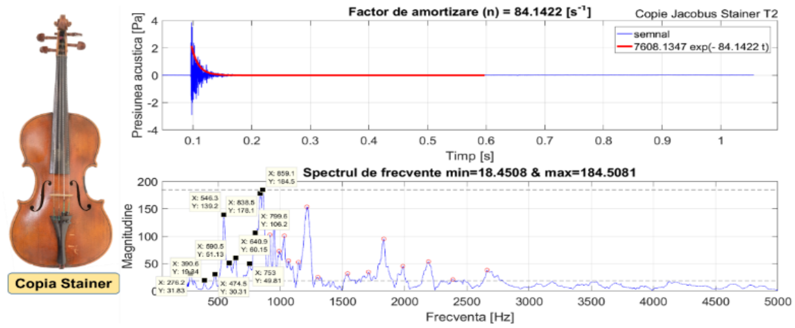
## 3. RESULTS, DISCUSSIONS AND CONCLUSIONS

### 3.1. The dynamic analysis for the excitation with the impact hammer

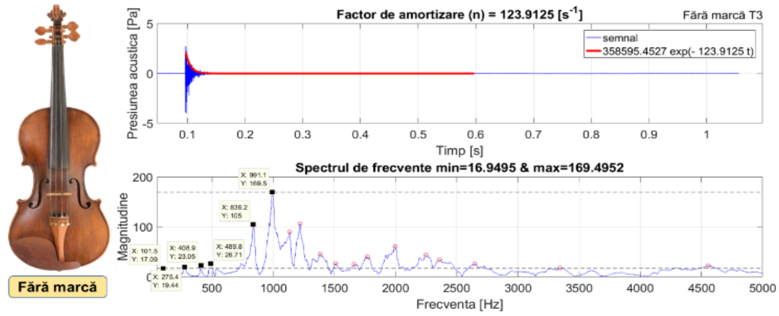
The excitation with the impact hammer test of the violins resulted in both the damping of the signal graphs and the frequency analysis, as presented in Figure 3.



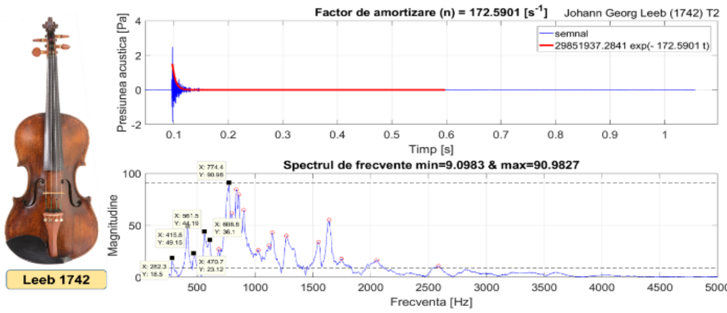

**a)**




**b)**




**c)**

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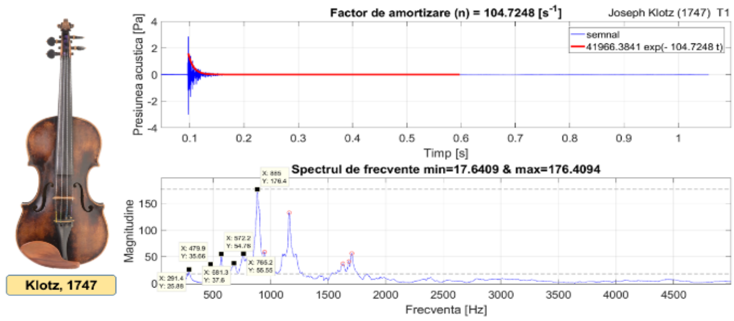


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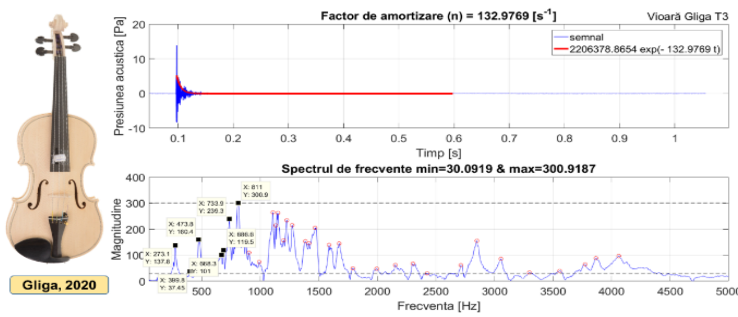



**f)**

**Figure 3**. Dynamic analysis of old violins: a) Babos Bela 1920 violin; b) Copy Stainer violin; c) Unbranded violin; d) Leeb violin, 1942; e) Klotz 1747 violin; f) Gliga 2020 violin

The eigenvalues for each violin were extracted (the first five natural frequencies, which are considered “signature mode” or “specific timbre” in the literature) and the dominant frequency $f_r$, these being subsequently analyzed comparatively (Table 1). Knowing the resonance frequency $f_r$ and its amplitude, the two frequencies $f_{r1}$, $f_{r2}$ will be extracted at 0.707 of the amplitude of the resonance frequency A, as seen in Figure 4. The relation of the logarithmic decrement will be as follows:

$$\delta = \frac{\pi (f_{r2} - f_{r1})}{f_r} \qquad (1)$$

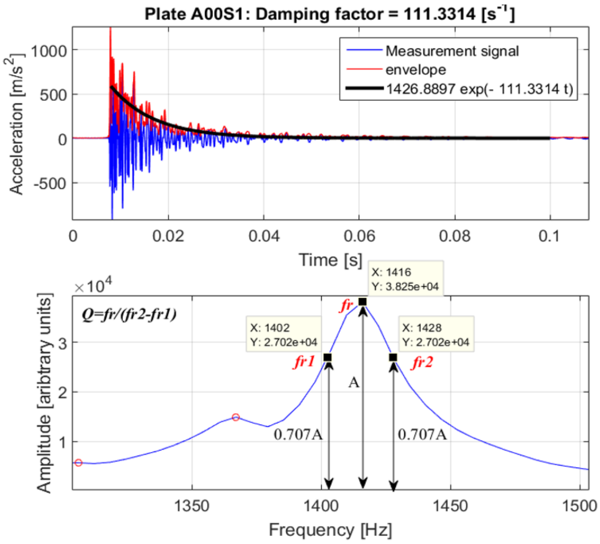



**Figure 4**. Determination of the quantities for the calculation of the logarithmic decrement and the quality factor

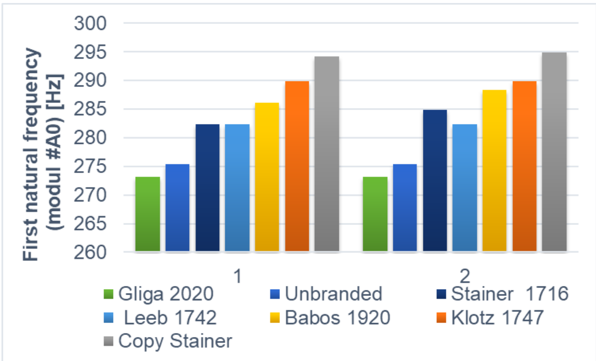
The quality factor Q (dimensionless) is a quantity related to the loss of vibrational energy by internal friction, leading to the phenomenon of sound damping, after the sound excitation has stopped. It was calculated with the relation:

$$Q = \frac{\pi * f_r}{(f_{r2} - f_{r1})} \qquad (2)$$

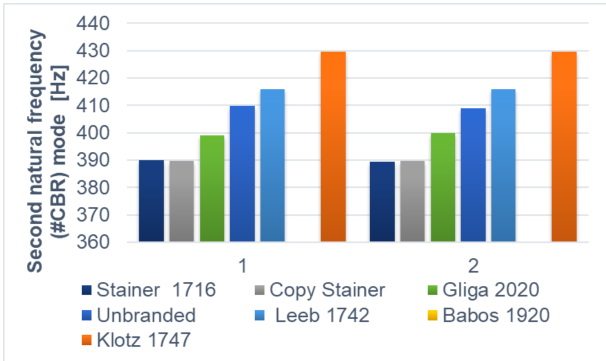
**Table 1:** The eigenvalues for the first five vibration modes of the old violins

| The studied violins | Symmetry of face rings* | The wave-length of the curly fiber (mm) | The frequency spectrum | | | | | Dominant frequency (Hz) fr | The quality factor Q | Damping tanδ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | f1 (A0) | f2 (CBR) | f3 (B1-) | f4 (B1+) | f5 | | | |
| **Unbranded T1** | 63.2 | 4.585 | 275.4 | 409.7 | 479.9 | 536.3 | 736.2 | 994.1 | 110 | 0.089 |
| **Unbranded T2** | 63.2 | 4.585 | 275.4 | 408.9 | 489.8 | 537.1 | 737.0 | 991.1 | 103 | 0.095 |
| **Klotz 1747 T1** | 65.8 | | 289.9 | 429.5 | 481.4 | 571.4 | 682.1 | 884.2 | 90 | 0.109 |
| **Klotz 1747 T2** | 65.8 | | 289.9 | 429.5 | 480.7 | 572.2 | 682.1 | 886.5 | 89 | 0.110 |
| **Copy Stainer T1** | 60.6 | 4.984 | 294.2 | 389.8 | 457.2 | 541.8 | | 541.8 | 107 | 0.092 |
| **Copy Stainer T2** | 60.6 | 4.984 | 294.9 | 389.7 | 460.1 | 547.0 | | 547.0 | 105 | 0.094 |
| **Babos 1920 T1** | 57.4 | 3.945 | 286.1 | | 489.0 | 534.8 | 593.6 | 827.8 | 83 | 0.118 |
| **Babos 1920 T2** | 57.4 | 3.945 | 288.4 | | 489.8 | 535.6 | 627.0 | 827.0 | 112 | 0.087 |
| **Leeb 1742 T1** | 61.3 | 6.421 | 282.3 | 415.8 | 470.7 | 561.5 | 608.1 | 774.4 | 72 | 0.136 |
| **Leeb 1742 T2** | 61.3 | 6.421 | 282.3 | 415.8 | 470.7 | 561.5 | 608.8 | 774.4 | 71 | 0.138 |
| **Gliga 2020 T1** | 61.5 | 6.731 | 273.1 | 399.0 | 473.8 | | 686.6 | 737.0 | 121 | 0.081 |
| **Gliga 2020 T2** | 61.5 | 6.731 | 273.1 | 399.8 | 473.8 | | 686.6 | 811.0 | 104 | 0.095 |
| **Stainer 1716 T1** | 62.7 | 4.021 | 282.3 | 389.9 | 449.2 | 603.3 | 857.0 | 603.3 | 68 | 0.145 |
| **Stainer 1716 T2** | 62.7 | 4.021 | 284.8 | 389.5 | 449.8 | 613.6 | | 613.6 | 76 | 0.130 |

Figure 5 compares the eigenvalues of the first vibration modes. The lowest natural frequency is recorded in the case of new violins (Gliga 2020 – 273 Hz), and the highest fundamental frequency is presented in the Stainer copy violin (295 Hz). From the point of view of the value ranges of the fundamental frequency (A0), the tested violins can be grouped in three categories: the violins with the frequency 275±5 Hz (Gliga 2020, Unbranded), those with a frequency of 280±5 Hz (Stainer 1716; Leeb 1716 and Babos 1920) and the violins with a frequency of 290±5 Hz (Klotz 1747 violin and Stainer Copy). In terms of signal convergence, the violins Klotz 1747, Leeb 1742, Unbranded and Gliga 2020 show convergent signals for the three tests performed. This first mode is the A0 mode, known as the vibration mode of the air in the violin body. In the case of mode 2, around the frequency of 400 Hz, the rhomboidal vibration mode is formed (known in the literature as the CBR mode) (Figure 5, b). In this case, the violins are divided into two groups: those with values below 400 Hz (390 - 400 Hz), respectively Stainer 1716 violins, Stainer Copy, Gliga 2020 and those with values above 400 Hz (400 - 430 Hz), Unbranded, Leeb 1742, Klotz 1747 violins, as can be seen in Figure 5, b. The Babos 1920 violin has no values specific to this mode. The signals are convergent for all violins tested in both tests, and the Stainer 1716 and Stainer Copy violins (about which there is not much data) show the same value as the CBR mode.




(a)

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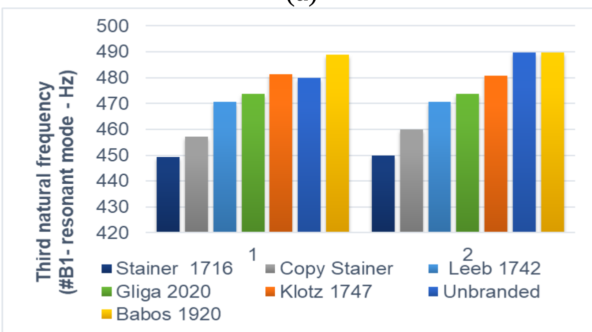


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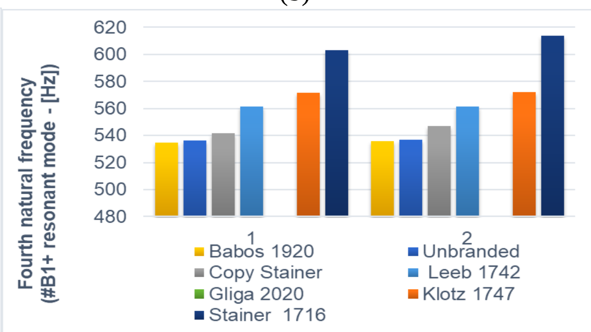
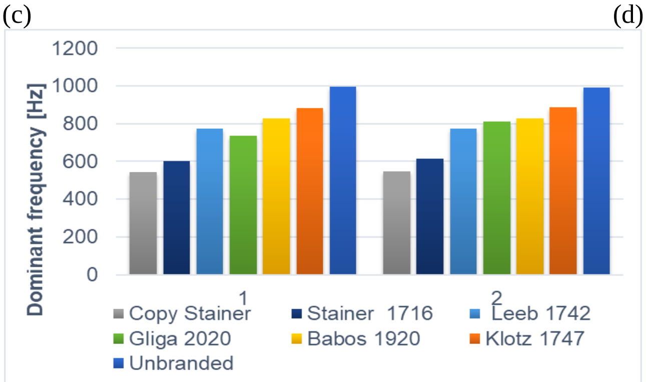



(d)

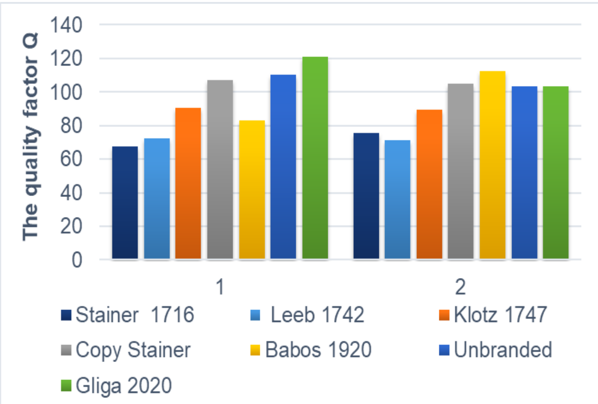



(e)

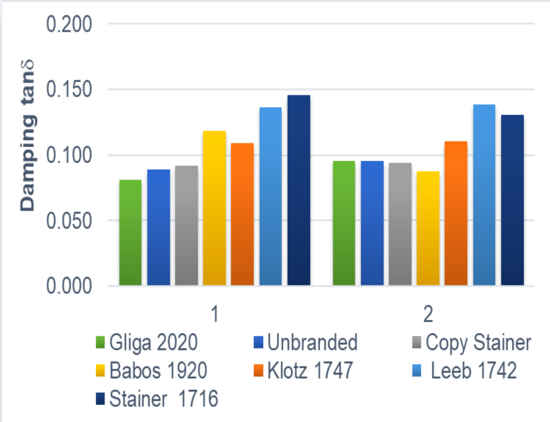
**Figure 5.** The eigenvalues of the first vibration modes, comparatively

For the next resonance mode (B1-), the eigenvalues are in the range 450 Hz - 490 Hz, the lowest values in this mode category being in the range 450 - 460 Hz, specific to the Stainer 1716 and Stainer Copy violins. The Leeb 1742 and Gliga 2021 violins form another group of values, with the mode frequency (# B1-) in the range 470 - 480 Hz, and the Klotz 1747, Unbranded and Babos 1920 violins record values in the range 480 - 500 Hz for the third mode, as seen in the graph in Figure 5, c.

In the case of B1 + bending mode, the eigenvalues are between 534 Hz and 620 Hz, as can be seen in Figure 5, d. The Babos 1920, unbranded and Stainer Copy violins have values in the 535 - 550 Hz range for this mode, while the Leeb 1742, Gliga 2020, Klotz 1747 violins record values in the range 560 - 580 Hz, a range identified as specific to this mode by Bissinger 2008. The Stainer 1716 violin has values approximately 7% higher than the average of the B1 + mode range, reported in the literature.
The dominant frequency, characterized by the maximum amplitude, has a wide range of values, being in the following ranges: 540 - 620 Hz for the Stainer 1716 and Stainer Copy violins, which leads us to assume that the Stainer Copy violin is indeed a Stainer violin due to the high degree of similarity of the frequency response. Between 770 - 820 Hz, there are the Leeb 1742 and Gliga 2020 violins, and in the range 820 - 900 Hz there are the dominant frequencies of the Babos 1920 and Klotz 1747 violins. The unbranded violin has the highest dominant frequency, around of 994 Hz (Figure 5, e). Comparatively analyzing the frequency response of old and new violins, it is found that old violins have a much richer and convergent frequency spectrum as a signal than the newer (new) violins. It can be stated that the modes that define the timbre of old violins such as Klotz 1747, Leeb 1742 are very well defined and convergent as signals when repeating the tests, compared to other violins. The Gliga 2020 violin presents the qualitative premises from a dynamic point of view to become an acoustic standard, with the passage of time (wood aging).
The Q quality factor defines the musical instrument's ability to dampen vibrations. The quality factor values for the analyzed violins are in the range 60 - 70, the lowest values being recorded for Stainer 1716, Leeb 1742 and Klotz 1747 violins (Figure 6, a), and the highest values are presented by the Stainer copy violins, Babos 1920, Unbranded, Gliga 2020, (Q = 100 - 121). Here, a hypothesis regarding the increase of the acoustic quality of old violins is given by Bucur, 2006. Thus, the wood aging process leads to a reorganization of the wood microstructure by recrystallization of cellulosic chains and a slight dissociation of cellulose molecules. Interestingly, the quality factor Q is inversely proportional to the age of the violins. Regarding the increase in damping, the relationship is directly proportional to the increase in the age of the violin (Figure 6, b).




(a)




(b)

**Figure 6**. The comparatiions between quality factor of analysed violins (a) and damping (b)

From the point of view of the correlation of the frequency response with the anatomical structure of the wood, it was observed that the symmetry of the face construction mostly affects the values of natural frequencies specific to CBR, B1 +, f5 and f6 modes, that increase with the improvement of face symmetry. The wavelength of the curly fiber specific to maple wood, found in the composition of the back of the violins, has a modest contribution in terms of the frequency spectrum, with a slightly sensitive influence on the first two modes of vibration (A0 and CBR). Thus, it was found that the value of the frequency f1 decreases, and that of the frequency f2 increases with the wavelength of the curly fiber. The contribution of the symmetry of the face halves and the wavelength of the curly fiber to the size variation of the probed acoustics was examined using the coefficient of determination, calculated on the assumption of a linear relationship between variables.

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