

# Determination of Elasticity of BF (Borassus Flabellifer) Leaf by Ultrasound

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**Abstract**—Elastic waves can be propagated through solids, resulting in the collective vibrations of the atoms and molecules in the medium. Ultrasonic is the most established technique to determine the elastic moduli of solids. It is one of the most widely used techniques to investigate phase transitions in solids. A numbers of ways of classifying defects that occur in solid wood or in wood-based materials are possible (Baucus, 1995). Non-destructive evaluation is an important tool for the characterization of wood and can be used in industry to improve quality control process through reducing the property variation of the raw material and its by-products. We used ultrasonic interferometer for measuring longitudinal and shear wave ultrasonic velocity in BF wood material and composite material of dried leaf powder made by Mittal Enterprises, New Delhi. The ultrasonic velocity was large in male BF wood and leaf material than female BF wood and leaf material. Longitudinal wave velocity decreased with increasing density of wood material which affects the Young's and shear modulus of the wood and leaf material.

**Keywords**—Anisotropic; Elastic Constant; Non Destructive Technique; Orthotropic; Piezoelectric Quartz; Resonant.

**Abbreviations**—Borassus Flabellifer (BF); Machines Stress Rated (MSR); Non Destructive Technique (NDT).

## I. INTRODUCTION

MANY of our modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics, and polymeric materials. This is especially true for materials that are needed for aerospace, under-water, and transportation applications. For example, aircraft engineers are increasingly searching for structural materials that have low densities, are strong, stiff, and abrasion and impact resistant, and are not easily corroded. This is a rather formidable combination of characteristics. Frequently, strong materials are relatively dense; also, increasing the strength or stiffness generally results in a decrease in impact strength [Agarwal & Broutman, 1].

Elastic waves can be propagated through solids, resulting in the collective vibrations of the atoms and molecules in the medium. The vibration characteristics of the atoms and molecules in the medium are determined by the interatomic forces. The nature of these forces is different in different solids and thus the wave propagation characteristics are also different. The wave propagation in a medium is characterized by its velocity and attenuation [Fedotov et al., 2]. The study of interaction of elastic waves with matter provides a great deal of information about their elastic properties. Accurate

values of the elastic constants is necessary to determine characteristic model parameters as lists of various atomic models of solids. The quantitative study of elastic constants and their variation with temperature and pressure given formation about the interactions of lattice vibrations and other elementary excitations in solids. They also provide a sensitive probe of structural phase transitions in solids. Ultrasonic is the most established technique to determine the elastic moduli of solids. It is one of the most widely used techniques to investigate phase transitions in solids. One unique advantage of the ultrasonic technique is that both static and dynamic properties can be measured simultaneously [Boyle & Sproule, 3]. Ultrasonic velocity measurements provide information about the equilibrium adiabatic properties of the system and the effects of temperature, pressure and external fields can be readily studied. Dynamic aspects of the theories of phase transitions also require information gathered from ultrasonic work. For the NDT [Hearmon, 4] in the composite material industry, it crucial to know the elastic properties such as Young's modulus, shear modulus, Poisson's ratio anisotropy, texture or stress. Ultrasonic techniques are often used to evaluate or nondestructively characterize such properties. Longitudinal and shear waves are broadly used for the purposes of non-destructive evaluation of materials and for generation and sensing of acoustic vibration of

surrounding. The increasing use of piezoelectric quartz for the stabilization of radio frequencies has promoted many investigations of the vibration of the quartz. Determination of the elastic properties of materials by means of measurements of ultrasonic velocity has a long history for different materials. Application of Ultrasonic techniques to wood appears to have been pioneered by Hermon [Musgrave, 5]. There is direct and continuing application of these analyses to the design and construction of musical instruments. The determination of the elastic properties of different wood species is also of importance in the more aspects of their use in the industry. The ultrasonic bulk wave velocity measurements; require the hypothesis of orthotropic symmetry, are used to determine these properties. The ultrasonic modes considered are longitudinal waves, and shear waves with particle motion along the direction of the applied stress. In fundamental research, it is of interest because of the insight it provides into the nature of the binding forces in solids [Hearmon, 6]. The relevant elastic constants also relate themselves. The elastic properties of a homogenous crystal are generally anisotropic. Even in the cubic crystal, the relationship between stress and strain depends on the orientation of the crystal axis relative to stress system [Schelleng, 7]. In wood Indus ultrasonic sensing has received considerable attention given its relatively low cost safety and versatility. A numbers of ways of classifying defects that occur in solid wood or in wood-based materials are possible (Baucus, 1995). Non-destructive evaluation is an important tool for the characterization of wood and can be used in industry to improve quality control process through reducing the property variation of the raw material and its by-products. The use of ultra-sonic technique for wood testing offers several advantages, including the low cost of equipment compared to that of Machines Stress Rated (MSR) and the relatively simple training in its use, which favor the method's easy dissemination at retailers and in the wood and by-product industry.

## II. PROCEDURE AND METHOD

The longitudinal axis of each specimen coincided with the longitudinal direction of the wood. The test specimens of BF Female and Male tree leaf and stem were kept under air-dried condition [Schumacher, 8]. Dried samples of leaf stem were cut in desired shape. We used adhesive Bond TITE made by ASTRAL Company. We used ultrasonic interferometer for measuring longitudinal and shear wave ultrasonic velocity in BF wood material and composite material of dried leaf powder made by Mittal Enterprises, New Delhi. Borassus Flabellifera BF Female and Male tree leaf stem wood Material was collected from Dhār district of Madhya Pradesh, India. Elastic moduli of solids are useful in understanding the nature of forces between the atoms or ions that constitute the solid. One of the methods used to study the elastic behavior of solids is the composite piezoelectric oscillator technique. It is simple to evaluate the Young's modulus (elastic constant). Measure the masses of the quartz rod and specimen using a

sensitive balance [Sasaki & Ando, 9]. Measure the length of specimen using the Venire calipers [Beloqui, 10]. Connect the ultrasonic interferometer for solid material with longitudinal and shear crystal holder and CRO. Insert the rectangular and cylindrical quartz rod in the crystal holder carefully without damaging the gold plating of the crystal such that the holder pins are approximately at the center of the plated electrode face of the crystal. Vary frequency and observe the stabilized oscillations above a particular value of resonant frequency  $R_f$ . Measure resonant frequency of the quartz rod ( $f_q$ ). Cement the quartz rod to the specimen, in the form of rectangular and cylindrical rod of identical cross-section. Now place the composite system in the crystal holder and by proper adjustment of  $R_f$ , measure the frequency of oscillations of composite system ( $f_c$ ) and minimum value of  $R_f$  that maintain oscillation as described above. In this case also the holder pins are approximately at the center of the plated electrode face of the crystal.



Figure 1: Ultrasonic Interferometer for Shear Wave Velocity



Figure 2: Ultrasonic Interferometer for Longitudinal Wave Velocity

### III. MATHEMATICAL BACKGROUND

In this technique, the specimen in the form of rectangular rod is cemented to quartz rod of identical cross section and the resonant frequency  $f_c$  of the composite system is determined using the apparatus [Auld, 11]. The resonant frequency of the quartz rod  $f_q$  is also determined. From knowledge of the  $f_q$ ,  $f_c$  and the masses of the quartz ( $m_q$ ) and the specimen ( $m_s$ ) the resonant frequency of the specimen  $f_s$  is evaluated using the relation.

$$f_s = f_c + (m_q/m_s)(f_c - f_s)$$

Using the value of  $f_s$  and the length of specimen  $L$ , velocity of ultrasonic waves on the specimen can be calculated by the relation:

$$V = 2L f_s$$

If we consider only longitudinal vibration, we know the velocity of longitudinal vibration in (100) direction given by

$$V_L = (c_{11}/\rho)^{1/2}$$

But we know by the definition,

$$E_1 = C_{11} \text{ and } E_s = C_{11}$$

$$E_1 = V_L^2 \rho \text{ and } E_s = V_s^2 \rho$$

From these relations we can find the Young's modulus and shear modulus for the specimen, where  $\rho$  is the density of the used material [Kothari, 12].

### IV. TABLE

1. The Ultrasonic Velocity and Elastic Constant of BF Female Plant Leaf for Rectangle Longitudinal Crystal						
Mass of Specimen (kg)	Volume (m <sup>3</sup> )	Density (k.g m <sup>-3</sup> )	Frequency Composite (kHz)	Frequency of Specimen (Hz)	Velocity (m/sec)	Elasticity Constant (Nm <sup>-1</sup> )
0.000534	4.92	1085.366	112.98	102139	5106.95	3.28E+10
2. The Ultrasonic Velocity and Elastic Constant of BF Female Plant Leaf Steam Wood for Rectangle Longitudinal Crystal						
Mass of Specimen (kg)	Volume (m <sup>3</sup> )	Density (k.g m <sup>-3</sup> )	Frequency Composite (kHz)	Frequency of Specimen (Hz)	Velocity (m/sec)	Elasticity Constant (Nm <sup>-1</sup> )
0.0004179	7.32E-07	580.8245	118.626	104309	7614.5	3.145E+10
3. The Ultrasonic Velocity and Elastic Constant of BF Female Plant Leaf for Cylindrical Longitudinal Crystal						
Mass of Specimen (kg)	Volume (m <sup>3</sup> )	Density (k.g m <sup>-3</sup> )	Frequency Composite (kHz)	Frequency of Specimen (Hz)	Velocity (m/sec)	Elasticity Constant (Nm <sup>-1</sup> )
0.000534	7.32E-07	1085.366	121.6887	118033	5819.47	3.587E+10
4. The Ultrasonic Velocity and Elastic Constant of BF Male Plant Leaf Stem Wood for Cylindrical Longitudinal Crystal						
Mass of Specimen (kg)	Volume (m <sup>3</sup> )	Density (k.g m <sup>-3</sup> )	Frequency Composite (kHz)	Frequency of Specimen (Hz)	Velocity (m/sec)	Elasticity Constant (Nm <sup>-1</sup> )
0.0004179	6.81E-07	580.8245	117.1113	103852	7158.45	3.275E+10
5. The Ultrasonic Velocity and Elastic Constant of BF Male Plant Leaf Steam for Rectangle Longitudinal Crystal						
Mass of Specimen (kg)	Volume (m <sup>3</sup> )	Density (k.g m <sup>-3</sup> )	Frequency Composite (kHz)	Frequency of Specimen (Hz)	Velocity (m/sec)	Elasticity Constant (Nm <sup>-1</sup> )
0.000497	4.60E-07	1076.97	119.21	111545	5146.27	2.90E+10
6. The Ultrasonic Velocity and Elastic Constant of BF Male Plant Leaf Wood for Cylindrical Longitudinal Crystal						
Mass of Specimen (kg)	Volume (m <sup>3</sup> )	Density (k.g m <sup>-3</sup> )	Frequency Composite (kHz)	Frequency of Specimen (Hz)	Velocity (m/sec)	Elasticity Constant (Nm <sup>-1</sup> )
0.00224	3.00E-07	7405.79	121.33	115751	5675.72	2.02E+10

## V. RESULT

In the elasticity energy principle to predict the elastic properties of the unidirectional composites [Bucur, 13], the specific shape and distribution mode of the reinforced phase and the matrix are not involved. So the elasticity energy principle has no practical value in the common fiber-reinforced composites [Hillier, 14]. The effect of density on ultrasonic velocity in wood and leaf and correlations between density, ultrasonic velocity and elastic constant were examined for BF wood, leaf (female and male) [Benabou, 15]. The ultrasonic velocity was large in male BF wood and leaf material than female BF wood and leaf material. Longitudinal wave velocity decreased with increasing density of wood material which affects the Young's and shear modulus of the wood and leaf material.

## VI. CONCLUSION

Composites are artificially produced multiphase materials having a desirable combination of the best properties of the constituent phases. Usually, one phase (the matrix) is continuous and completely surrounds the other (the dispersed phase). In this discussion, composites were classified as particle-reinforced, fiber-reinforced, and structural. The value of the ultrasonic velocity depends on the wood, leaf density and also showed that the elastic constant depends on the ultrasonic velocity [Chen et al., 16]. The results obtained and analyses carried out, therefore, allow us to conclude that the non-destructive ultrasound based method can be employed to obtain reliable evaluations of the mechanical properties of leaf and wood.

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