THE CHARACTERISTICS OF BASEBALL BATS MANUFACTURED BY DIFFERENT MATERIALS

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Bamboo is a new material to manufacture baseball bat which has the low cost and fast life cycle advantages. But there is no research has been done to study the performance of bamboo bat. This research used three non-destructive testing (NDT) methods including ultrasonic testing method, stress wave testing method and tap tone frequency analysis system (TTFAS) to determine the performance difference among different bat materials. The testing specimen were five baseball bats using four different materials (bamboo, bamboo& wood, wood, and aluminum). The results showed that there are significant correlations among three NDT methods in bats transmit velocities. Therefore, TTFAS method was selected to analyze the characteristics of different material baseball bats because of its low cost and simplicity for the experiment. The results showed the longitudinal and transverse first natural frequencies for each material and the longitudinal and transverse dynamic modulus of elasticity (MOEd). Based on dynamic modulus of elasticity, the stiffness of aluminum bats was higher than the others.

KEY WORDS: baseball bat, dynamic modulus of elasticity, stiffness, bat material

INTRODUCTION: Modulus of elasticity (MOE) is one of the most important mechanical characteristics to evaluate strength of wood. Cho (2000) did a study to determine the strength variation of Japan Cedar, found that the correlation coefficient between MOE and MOEd was 0.82. Thus, MOEd could replace MOE to evaluate strength of wood. Since the time to do NDT testing was shorter than traditional bending testing. Furthermore, the NDT method can determine bat's longitudinal and transverse natural frequencies. Therefore, NDT method can be used as an useful index to estimate material strength.

Bats stiffness is one of strength index for the bats. Adair (1990) pointed out that the elastic modulus of hickory was about twice of ash, the stiffer hickory bats vibrated with a smaller amplitude and higher frequency. Brody (1986) stated out that the frequency of this oscillation was measured using a microphone, audio amplifier and an oscilloscope. Therefore, this study measure impact frequency to determine bats' stiffness using a microphone.

METHODS: The testing specimen were five baseball bats using four different materials(bamboo, bamboo & wood, wood, and aluminum).This study used three NDT methods including ultrasonic testing method, stress wave testing method and TTFAS to determine the performance difference among different bat materials. Therefore, TTFAS method was selected to analyze the characteristics of different material baseball bats because of its low cost and simplicity for the experiment. These testing methods were showed in Figure 1 and Figure 2. The frequency of this oscillation was measured using a microphone, audio amplifier, and an oscilloscope, then the data were analyzed by cool edit 2000 software and showed in Figure 3, And then used Fast Fourier Transform (FFT) to transform the signals from time domain to frequency domain, the result of frequency domain was displayed in Figure 4.

TTFAS method applied stress wave in the material to analyze that natural frequency. This study used longitudinal and transverse first natural frequencies to estimate longitudinal and transverse dynamic modulus of elasticity. The longitudinal and transverse MOEd formula shown as follows:

Longitudinal oscillate formula:

$$V = 2 \cdot f \cdot l$$

$$E_l = V^2 \cdot \rho$$

and the transverse oscillate formula:

$$E_t = \frac{4\pi^2 \cdot f \cdot l^4 \cdot A \cdot \rho}{\beta^4 \cdot I},$$

Where
V: velocity (m/s),
f: frequency (Hz)
l: bat length (m),
ρ:bat density (kg/m^3),
A: cross-sectional area (m^2)
β: boundary coefficient ; free-free fixed β=4.75
I: inertia distance, $\frac{\pi \cdot D^4}{64}$ (m^4),
E_l: longitudinal modulus of elasticity(GPa),
E_t: transverse modulus of elasticity(GPa).

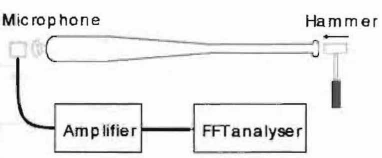

Figure 1 Longitudinal TTFAS method.

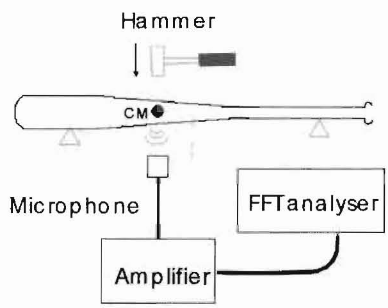

Figure 2 Transverse TTFAS method.

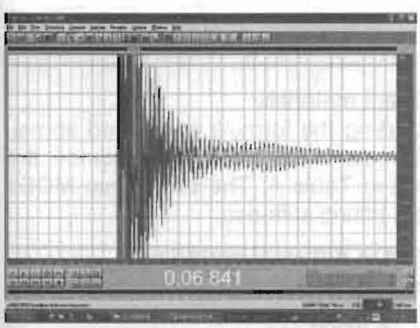

Figure 3 Cool Edit 2000 oscillation.

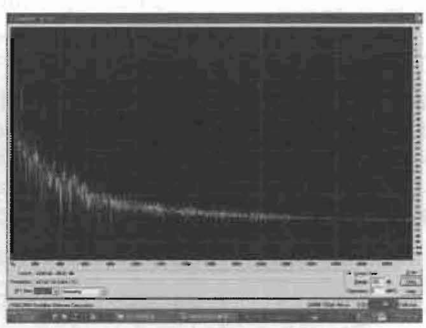

Figure 4 FFT analyze results.

RESULTS:

1. Three NDT methods longitudinal velocities correlation:

The study used ultrasonic testing equipment, stress wave testing and TTFAS to know about the relationship between the three methods. The testing results were summarized in Table 1, Table 2. Based on the longitudinal velocities could develop a testing method with bats strength.

Table 1 Three NDT methods longitudinal velocities.

	Bamboo I	Bamboo II	Bamboo& wood	Wood
Ultrasonic velocity(m/s)	4365.16	4271.90	4460.49	5164.83
Stress wave velocity (m/s)	4205.92	4147.76	4268.34	4965.61
Tap tone frequency velocity(m/s)	3560.50	3466.98	3581.45	4436.17

Table 2 Correlation of three NDT methods.

	Ultrasonic VS Stress wave	Ultrasonic VS TTFAS	Stress wave VS TTFAS
correlation	0.981	0.969	0.931

2. Compared longitudinal and transverse first natural frequencies in different materials: Used different materials each group for three bats and one aluminum bat was compared with the other. The testing results were displayed in Table 3. Bamboo bats', Bamboo & wood bats' longitudinal and transverse first natural frequencies were 2042 Hz~2102 Hz, 109 - 121 Hz. Wood bats' were 2615 Hz, 159.7 Hz. Aluminum bats' were 2583 Hz, 226 Hz. Wood bats' results were similar to Brody (1990), Nathan (2000) and Rod Cross (1998). Aluminum bats' results were also similar to Brody (1986,1990).

Table 3 Longitudinal and transverse first natural frequencies in different materials.

	Bamboo I	Bamboo II	Bamboo& wood	Wood	Aluminum
Longitudinal first natural frequencies (Hz)	2102.66 (30.89)	2042.66 (138.60)	2084.66 (61.20)	2614.66 (220.66)	2583
Transverse first natural frequencies (Hz)	121.00 (1.768)	109.66 (2.29)	117.73 (4.675)	159.7 (9.929)	226

3. Compared longitudinal and transverse MOEd in different materials:
Longitudinal and transverse MOEd could be calculated using the formula mentioned above. Transverse MOEd was calculated using cylindrical formula since we have assumed the geometry of bat was cylinder. The results were showed in Table 4. The transverse MOEd could be a norm for reference, because that effected bats hitting stiffness.

Table 4 Longitudinal and transverse MOEd in different materials.

	Bamboo I	Bamboo II	Bamboo & wood	Wood	Aluminum
Bat density (kg/m^3)	647.54	719.65	651.59	654.30	555.87
Longitudinal velocity *(m/s)*	3560.50	3466.98	3581.45	4436.17	4323.94
Longitudinal MOEd (Gpa)	8.21	8.66	8.36	12.94	10.39
Transverse MOEd (Gpa)	2.51	2.297	2.296	4.133	6.13

DISCUSSION: This investigation as the NDT testing methods applied different materials to effect longitudinal and transverse first natural frequencies. The results showed that there are significant correlation among three NDT methods in bats transmit velocities.

Longitudinal and transverse first natural frequencies in different materials were showed: Bamboo, Bamboo& wood longitudinal and transverse first natural frequencies were much similar, Aluminum longitudinal first natural frequencies were lower than wood, because the plastic cement restricts the stress wave transmission in aluminum bats. Transverse first natural frequencies were showed: Aluminum bats transverse first natural frequencies were higher than the other. TTFAS method was showed: Longitudinal and transverse first natural frequencies had variance in different materials.
Longitudinal and transverse MOEd in different materials were showed: The longitudinal and transverse dynamic modulus of elasticity (MOEd)of Bamboo bats were 8.21 - 8.66 GPa and 2.29 - 2.51 GPa, bamboo & wood bats were 8.36 GPa and 2.96 GPa, wood bats were 12.94 GPa and 4.13 GPa, aluminum bats were 10.39 GPa and 6.13 GPa. Based on dynamic modulus of elasticity, the stiffness of aluminum bats was higher than wood bat, bamboo & wood bat, and bamboo bat.

CONCLUSION: The NDT methods could estimate bat hitting performance, aluminum bats' strength more than the others. The NDT method can be used as an useful index to estimate material strength.

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