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THE NON-DESTRUCTIVE METHOD OF HARDBOARD STRENGTH TESTING

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ABSTRACT

The standard method of wood fiberboard panels (hardboard panels) strength testing is such, that bending strength is being determined by bending a specimen placed on supports until it breaks, and the maximum bending (breaking in two) force is measured.

The non-destructive ultrasonic Lamb wave's method measurement method for determination of hardboard bending strength (modulus of rupture) is offered. The essence of this method is that the velocity propagation of ultrasonic waves depends upon their propagation environment Young modulus, density and Poisson's ratio. The symmetric Lamb waves have a very good feature; their velocity does not depend upon thickness of the sheet when thickness is less than wavelength.

On the basis of the obtained results there has been developed the hardboard strength measurement instrument. From the general data multitude there have been obtained regression equations for machine-direction and cross-direction cases.

The measurement results by standard method and by ultrasonic method were compared. The difference of total measurement results was verified by calculation the Student's criteria. If the significance level p= 0.05 (n=825) then one may affirm that the measurement results are statistically reliable also for measurement in machine-direction of hardboard and in cross-direction of it.

KEY WORDS: fiberboard, non-destructive testing, bending strength

INTRODUCTION

When manufacturing wood based hardboard (fiberboard) panels one should retain in the permissible limits all their shown parameters. To secure these parameters and effective control of the production process there is necessary information about their basic parameters already in the very production line. Therefore there should be available effective methods of these hardboard parameters determinations, based upon non-destructive testing. In this article the non-destructive measurement method for determination of hardboard bending strength (modulus of rupture) is offered.

MATERIAL AND METHODS

Standard determination method of bending strength

One of the most important hardboard panels (HBP) technical parameters is their bending strength (in MPa), which is determined by breaking in two (500x50 mm) specimen by a special arrangement (in many countries, where are manufactured hardboard, this method has been legalized by national standard) [1], [2].

Bending strength is being determined by bending a specimen placed on supports until it breaks, and the maximum bending (breaking in two) force P_{max} is fixed.

Strength is assessed by bending tensions corresponding maximum specimen breaking in two force P_{max}:

$$\sigma_b = \frac{1{,}5P_{\max}}{b}\frac{l}{h^2}\ , \tag{1}$$

where l – the distance between supports,
h – the thickness of the sample,
b – the width of the sample,
P_{max} – the force of breaking in two.

In order to determine bending strength by this method one should cut out four specimens from various HBP places (each of them from different HBP quarter): two specimens are being cut out along the HBP, i.e. in the machine direction, the other two- in cross-direction. One from each specimen couples is broken from one side (face), the other- from other side. The HBP bending strength is determined, having calculated the average strength value out of four specimens.

The relative extended bending tensions uncertainty may be expressed on the basis of (1) as

$$U_\sigma = 2\cdot\sqrt{\left(\frac{\Delta P}{P}\right)^2+\left(\frac{\Delta l}{l}\right)^2+\left(\frac{\Delta b}{b}\right)^2+\frac{1}{3}\left(2\frac{\Delta h}{h}\right)^2}\ , \tag{2}$$

where $\frac{\Delta P}{P}$, $\frac{\Delta l}{l}$ and $\frac{\Delta b}{b}$ are the relative standard (corresponding for a force, distance between supports and specimen width) measurement uncertainties; □h is the quantization error of the specimen thickness measurement; the error distribution is regarded to be even.

In reality, during the measurement of strength we attain

$$\frac{\Delta P}{P} = 10^{-2}\ ;\ \frac{\Delta l}{l} = 2\cdot 10^{-3}\ ;\ \frac{\Delta b}{b} = 10^{-2}\ ;\ \Delta h = 0.1\text{mm}.$$

Then, when h=3mm, we obtain

$$U_\sigma = 7.5\cdot 10^{-2}$$

If = 40 MPa (typical value) [3] then at the probability 0.95 real value will be

$$37\ \text{MPa} < \sigma_b < 43\ \text{MPa}$$

Lamb waves method

The essence of this method is that the velocity propagation of ultrasonic waves depends upon their propagation environment Young modulus, density and Poisson's ratio. The symmetric Lamb waves have a very good feature; their velocity does not depend upon thickness of the sheet when thickness is less than wavelength. Then velocity may be expressed as

$$v = k\sqrt{\frac{E}{\rho}}, \tag{3}$$

where v – velocity of ultrasonic waves propagation,
E – the material elasticity modulus,
ρ – the material density,
k – the proportionality coefficient.

Taking into account this fact and also initial investigation results during which was examined Lamb waves excitation, damping when propagating and their frequency features, there has been chosen frequency about 50 kHz and measurement base 400 mm.

The wave propagation time T_x is measured from the transmitter impulse start till the receiver signal passing through null level.

The measurement uncertainty of this duration U_{Tx} consists of the following basic components: component U_{T0} that causes passing through "null" moment determination in a comparator, digital measurement technique stipulated quantization component U_{Tk} and a component for measurement basis change (instrument positioning, surface influence, etc.) U_{Tl}. The distribution of the component U_{Tk} is kept to be even, while others components distributions – normal.

Thus, the extended uncertainty of the propagation time measurement is

$$U_{Tx} = 2 \cdot \sqrt{U_{T0}^2 + \frac{1}{3}U_{Tk}^2 + U_{Tl}^2} \; . \tag{4}$$

Considering that the standard uncertainty of the base l is U_l = 0.22 mm, the velocity in the sheet is 2200 m/s, we obtain $U_{Tl} = 10^{-7}$ s.

We easily obtain U_{Tk} 10^{-8} s.

By measuring propagation time close to the HB edge or in the band like HB specimen, due to reflections the received signal may be distorted, and at the same time passing through "null" moment may be determined incorrectly. Such a situation is very difficult to be assessed. Therefore we shall limit ourselves so the assessment of the comparator stipulated $U_{T0}=10^{-8}$ s.

Then

$$U_{Tx} \approx 2{\cdot}10^{-7} \text{ s.}$$

The potential accuracy of non-destructive method

To relate propagation time with strength theoretically would be very difficult because the flight-of-time and strength both depend upon many factors, which in the manufacture process are not controlled. Therefore there remains only one way of this relation determination-experimental. Having done many tests, there have been determined propagation time and strength related equations, which may be expressed as

$$\sigma = A - B \cdot T_x \tag{5}$$

where A and B are the coefficients. The coefficients depend upon the kind of hardboard and fiber orientation. In general, the expanded measurement uncertainty of the indirect measured strength comes from (5):

$$U_\sigma = B \cdot U_{Tx}. \tag{6}$$

The expanded uncertainty of the propagation time is

$$U_{tx} \approx 2 \cdot 10^{-7} \text{ s, i.e. } 0{,}2\ \mu\text{s}.$$

Then the expanded uncertainty is

$$U_\sigma = 0.2 \cdot B. \tag{7}$$

There has been experimentally determined that hardboard strength in the machine-direction is

$$\sigma_{MD} = 153 - 0.624 \cdot T_x, \tag{8}$$

and in cross-direction

$$\sigma_{CD} = 206 - 0.882 \cdot T_x. \tag{9}$$

Thus, $B_{MD} = 0.624$, and $B_{CD} = 0.882$.

When strength $\sigma = 40$ MPa [3] due to indirectly measured uncertainty, strength intervals with probability 0.95 will be:

$$39.87 < \sigma_{MD} < 40.13,$$

$$39.82 < \sigma_{CD} < 41.86.$$

As was mentioned above such are possibilities of the method. In reality, we may expect to obtain several times wider interval.

Cross correlation of the standard and new method measurement results

Correlation R_{xy} between the obtained results x_i by standard method and measuring the same specimens by new method obtained results y_i is as follows:

$$R_{xy} = \frac{\sum_{i=1}^{N} (x_i + \Delta x_i)(y_i + \Delta y_i)}{\sqrt{\sum_{i=1}^{N} (x_i + \Delta x_i)^2 + \sum_{i=1}^{N} (y_i + \Delta y_i)^2}}, \tag{10}$$

where Δx_i and Δy_i are random measurement errors.

Considering that errors dispersion is $S^2_{\Delta x} = S^2_{\Delta y} = S^2_{\Delta}$ and measured strength dispersion $S^2_x = S^2_y = S^2$, we obtain

$$R = \frac{1}{1+\alpha^2}, \qquad (11)$$

where $\alpha = S_{\Delta} / S$.

During experiments we had $S_x \approx 10$ and $S_{\Delta} \approx 4$. Then

$$R = \frac{1}{1+(0.4)^2} = \frac{1}{1.16} \approx \square.\square 1$$

On the basis of the obtained results there has been developed hardboard strength measurement instrument [4].

Main characteristics of the measurement instrument:

1. Measuring hardboard strength in machine-direction and in cross-direction
2. Strength measurement limits 20 … 50 MPa
3. Strength measurement uncertainty 2 MPa
4. Ultrasonic Lamb wave propagation duration measurement limits 100 … 250 μs
5. Memory (number of measurements) 250

RESULTS AND DISCUSSION

All specimens' strength measurements were carried out by a standard and ultrasonic method. Different operators at different time carried out more than 800 measurements. For illustration cross correlation between bending strength measured by standard method and Lamb waves propagation time measured by hardboard strength meter in of the first specimen group is shown in Fig. 1.

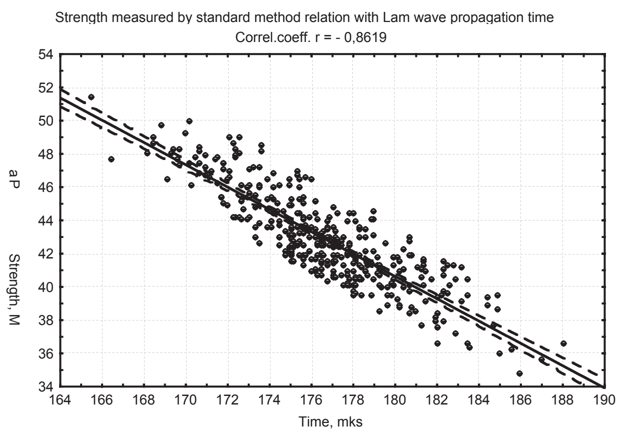

Fig. 1: Cross correlation between bending strength measured by standard method and Lamb waves propagation time measured by hardboard strength meter in machine-direction (n=459)

The second group of specimens (n=366) were measured after one month.

In both measured specimen groups there has been determined a strong correlation relation between hardboard bending strength, and Lamb waves propagation time both in the specimens cut out in machine-direction and in specimens cut out cross-direction it. Data dispersion in both groups is of the same order; therefore the data of both measurement groups have been combined.

From the general data multitude there have been obtained regression equations for machine-direction and cross-direction cases:

$$\sigma_{MD} = 153.32 - 0.6238\, T_{MD}, \quad (14)$$

$$\sigma_{CD} = 206.0 - 0.8820\, T_{CD}. \quad (15)$$

The calculated on the basis of these equations measurement results comparison with standard measurement results shows that ultrasonic hardboard strength measurement method according to the statistic average of the obtained measurement data and uncertainty interval is not worse than the standard strength determination method (breaking samples in two).

By carrying repeated measurements by ultrasonic method after several months, there was noticed that hardboard strength in the course of time increases. This result does not contradict the results obtained by standard method.

To compare of the results by standard method and by ultrasonic method (rejecting the measurement results with gross mistakes) data are given in Table 1.

Tab. 1: Comparison of the resuls by the method of measurement

Method of measurement	Strength of specimen cut of in machine-direction of HB, MPa	Strength of specimen cut of in cross-direction of HB, MPa
First group of specimen		
Standard method	42.82 ± 2.92	40.75 ± 3.15
Ultrasonic	42.92 ± 2.44	40.55 ± 2.29
Second group of specimen		
Standard method	42.36 ±3.56	40.16 ±4.16
Ultrasonic	42.38 ± 2.38	40.3 ± 2.84
Total measurement results		
Standard method	42.62 ± 3.23	40.55 ± 3.64
Ultrasonic	42.68 ± 2.43	40.44 ± 2.55

The difference of total measurement results was verified by calculation the Student's criteria. If the significance level p= 0.05 (n=825) then one may affirm that the measurement results are statistically reliable also for measurement in machine-direction of hardboard and in cross-direction of it.

CONCLUSIONS

1. Ultrasonic strength measurement method may be used for an effective hardboard strength testing and in assessing its distribution in a panel. The method may be actualized in a manufacturing line.
2. Although the main investigation was carried out on the basis of hardboard, however, ultrasonic method may be also applied to other panels. This is proved by initial experiments with wood particleboard.
3. Hardboard strength measurement by standard method breaking in two and by ultrasonic method data statistic averages practically coincidence with each other.
4. Measurement results difference of some specimens occur due to the following causes:
   - random standard and ultrasonic measurement errors;
   - in narrow specimens there are side reflections. Therefore ultrasonic measurement instrument should be positioned in the centre of a specimen. Measuring in large hardboard panels errors due to reflections were not found;
   - Ultrasonic measurement method presents integrated strength value between measurement point (the distance between points was 400 mm), while standard method presents local strength value in the breaking place.

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