INDENTATION HARDNESS FOR LOW DENSITY MATERIALS

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Abstract – There is a demand of a system for the non-destructive control of one of the basic quality parameters for wood-based low-density boards (Softboard). A relatively non-destructive method was analyzed on a purpose to find a parameter to measure that has the biggest possible correlation with the bending strength. 13 different softboards were investigated using two different techniques. The boards were tested using another two non-destructive methods: velocity measurement of ultrasonic Lamb waves and impact parameters measurement. Out of all experiment results the highest correlation between bending strength and the conical indenter impact pulse peak force was found.

Keywords: softboard, indentation hardness.

1. INTRODUCTION

Wood-based low-density board (Softboard) is a wood-based panel, which is known as a material for house wares, automotive and construction, etc. Recently, they have developed rapidly. Wood-based panel products are considered environment friendly because they typically use recycled materials. Moreover the fact that softboard can be found in a wide range of densities from 40 to 980 kg/m^3, depending on the average size and the wall thickness of cells, it provides so desired flexibility in design.

Most softboards consist of a fibrous web structure that is principally composed of cellulose polymer refined from wood fibers by a chemical pulping process [1]. The fibers are then formed into a stochastic web structure during the softboard making process that result in a porous fibrous network bound together by polymer bonding. This porous structure typically has from 30 to 60% void volume. The mechanical properties of these materials depend primarily on the degree of bonding, the organization of the fiber structure and the fiber's morphological and polymer characteristics. The obtained softboard is typically anisotropic in three dimensions (in plane or out of plane) due to anisotropic nature of the fibers, alignment of the fibers while forming and interval stress imparted while manufacturing the softboard, especially while drying.

The present investigation introduces an indentation method as a mean for determining the local hardness and compressive elastic modulus of the softboard.

Besides the bending strength and the elastic modulus the indentation hardness is an important mechanical property of the softboard in the field of quality control of boards manufacture. As well as the other mechanical properties, the indentation hardness of low-density materials depends on the state of consolidation.

The present paper proposes a simplifying assumption - the homogeneity of the softboard. Yet, tested softboards displayed heterogeneity of the density distribution on the scale of the sample size (approx. 1x1 meter). The pressure susceptibility determines the degree of porosity reduction under pressure (compressibility) and the maximal hardness provides a measure of bonding strength that is necessary for the formation of the softboard.

We split the indentation method into two techniques. The first technique called continuous indentation involves pressing an indenter into a material, while recording the resistive force as a function of the indenter instrument displacement while pricking in and out the indenter. The second technique involves the impact of conical indenter of two geometries (120 and 80 degrees) while recording the resistive force as a function of the indenter instrument displacement.

2. EXPERIMENTAL

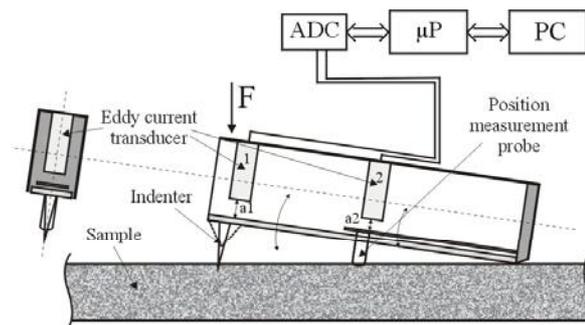The principle of the first technique is shown in the 1st figure.

Fig. 1. Working principle of continuous indentation testing.

The indenter is pricked in and out of the softboard while the change of the force and the depth is measured during the process. A two types of indenters were used: a 10 degrees conical and a 90 degrees 1 mm thickness plate. Measurement is implemented by two Eddy current transducers, which outputs are proportional to the bend of the metallic plates holding the indenter and the depth measurement probe. Signals from both channels are

converted into digital form and sent to the computer. The non-linearity is corrected during the calibration.

An example of the force and depth vs. time graphs shows the figure 2. The force and depth graphs are hitchy because of the fiber-based board structure. Out of these graphs the depth-force graph is obtained. The figure 3 shows depth-force graphs of different density softboards.
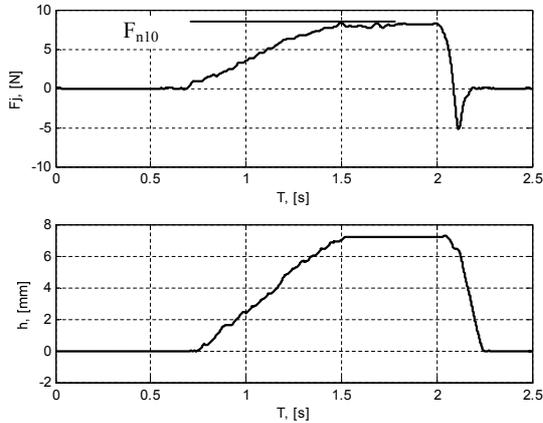

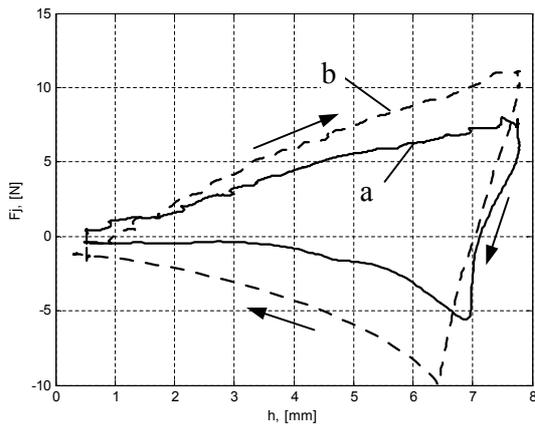Fig. 2. An example of the force and depth vs. time graphs, obtained with continuous indentation method.

Fig. 3. A - softboard with the density of 246 kg/m^3, b – softboard with the density of 260 kg/m^3 (a – graph obtained out of fig. 2 graphs).

Out of the figures 2 and 3 it is possible to evaluate these informative parameters:

1) Maximum resistive force when pricking in F_{in};
2) Maximum resistive force when pricking out F_{out};

The advantages of this method are that the method is operative and practically non-destructive. Disadvantages are the locality of the method and the scatter of the results. The local strength and the friction force, which is relevant in some cases of the practical use of the softboards are evaluated with this method.

There are two sets of experimental data listed in the table I - a maximum resistive force F while pricking in with a static force: F_{n10} - when the 10 degrees conical indenter is on and F_{n90} – when the 90 degrees 1 mm thickness plate is on.

Another technique employs 80 and 120 degrees conical indenters. According to the principle that is shown in the figure 4 the force and depth time graphs were measured [4,5].
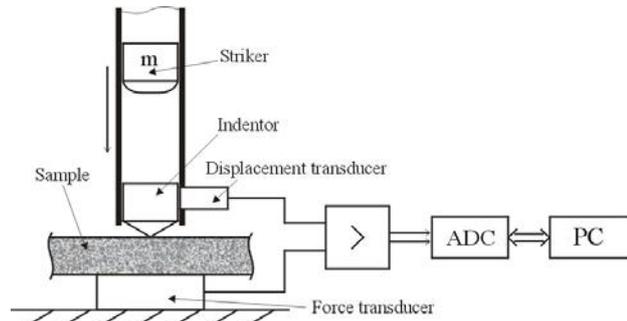

Fig. 4. Working principle of tester with conical indenter.

The displacement was measured using an optical transducer with the resolution of 2μm and the force was measured using a piezoelectric transducer, which can sense a dynamical force up to 2kN.

Fig. 5. An example of the force and the depth vs. time graphs, obtained with the 80 degrees conical indenter tester.

Fig. 6. An example of a depth-force graph of the sample tested with the 80 degrees conical indenter.
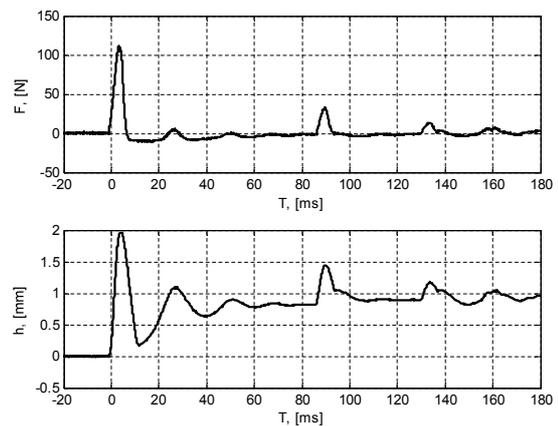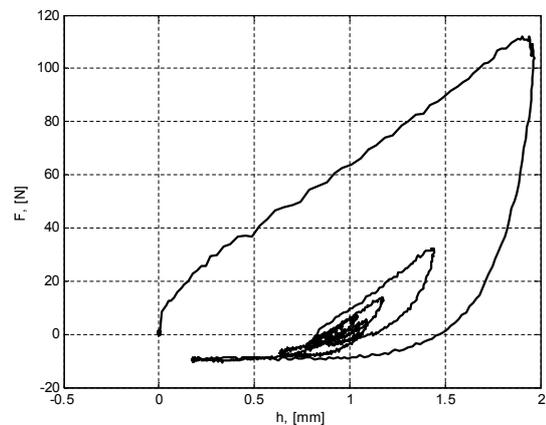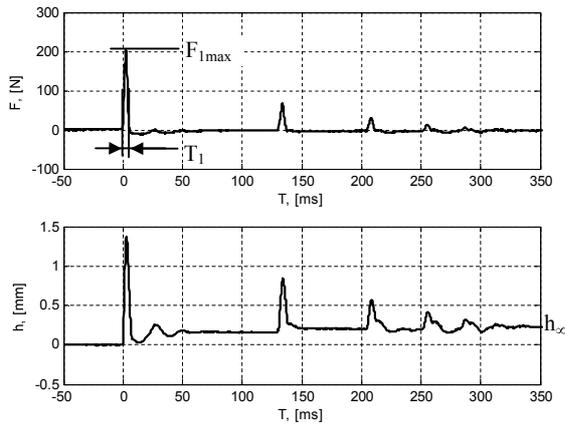
Fig. 7. An example of the force and the depth vs. time graphs, obtained with the 120 degrees conical indenter tester.
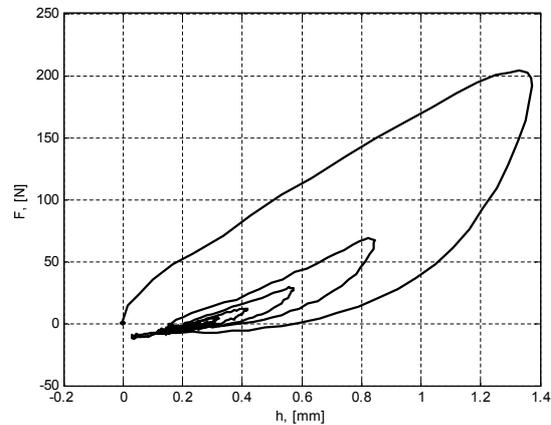

Fig. 8. An example of a depth-force graph of the sample tested with the 120 degrees conical indenter.

The transitional process for both transducers does not exceed 50μs. A 12bit 1Msample/s transducer was used for analog-digital conversion.

Out of the figures 5 and 7 graphs it is possible to evaluate these informative parameters:

1) Maximum force of the first and the second impact F_{1max}, F_{2max};
2) Maximum depth h_{max};
3) Time duration between the first and the second force peaks t_1-t_2;
4) Time durations of the first and the second force impulses (impacts) T_1, T_2;
5) Settled depth h_∞.

An example of depth-force graph is shown in the figures 6 and 8 (for the 80 degrees conical indenter and the 120 degrees conical indenter). The experimental data and correlation coefficients for the conical indenter of 120 degrees are listed in the table I.

3. OTHER WOOD BASED BOARD TESTING METHODS

3.1. Standard method for the bending strength measurement

For the objective bending strength evaluation of the sample the common three-point bending technique was used [3]. The uncertainty of this method implemented in our laboratory reaches 5%. The advantage of the method is that it directly evaluates the bending strength. Disadvantages are that it is a destructive method; it evaluates localized bending strength. The experimental data is listed in the very last column of the table I.

3.2. Non-destructive testing methods

We investigated two non-destructive methods:
- Speed measurement of ultrasonic Lamb waves;
- Impact parameters measurement method.

The velocity of ultrasonic Lamb waves is equal to:

$$v_l = k_v \sqrt{\frac{E}{\rho}}, \qquad (1)$$

where k_v – coefficient, E – Young modulus, ρ - density.

Lamb waves transducers and the instrument we had made where used to measure the speed. The uncertainty of this method does not exceed 1%. The advantage of the ultrasonic Lamb waves method is that the speed of waves is measured precise and quickly along the chosen line. So we get the average strength of the board along that line. Further more, this method makes it possible to evaluate bending strength dependency on the direction of the board. That means anisotropy, which can reach tenths of percents.

Impact method [2] is based on the duration of impact to the board dependency on mechanical characteristics:

$$T = k_T \sqrt{\frac{m}{k_c}}, \qquad (2)$$

where k_T – coefficient, m – striker mass, k_c – the rigidity of contact zone.

Impact duration relative uncertainty does not exceed 0.1%.

The advantages of this method are speed and short time measurement contact, which makes the system possible to implement on moving samples. Unlike the indentation striker this instrument does not leave any trace on the softboard.

4. RESULTS AND DISCUSSION

We investigated samples from two different manufacturers. Number 1 –5 samples in the table I represent the first manufacturer and the samples 6 – 13 represents the second manufacturer.

The 1st column lists densities of the samples and the 2nd lists thickness.

Table I. Measurement results and correlation coefficients comparison. F_{1max}, T_1, h_∞ - measured with the 120 degrees conical indenter.

Nr.	ρ, kg/m3	h_{th}, mm	F_{n10},N	F_{n90}, rel. units	F_{1max}, N	T_1, ms	h_∞, mm	v, m/s	T, µs	σ, MPa
				Measured parameter						
1	266	6,3	8,8	756	287	17,5	0,8	1802	2386	1,47
2	263	12,3	14,6	852	208	18,5	1,0	1602	2686	1,16
3	260	6,5	14,2	753	291	16,5	1,5	1802	2558	1,50
4	251	25,5	9,1	712	108	20	0,9	1522	2960	0,80
5	246	12,2	7,9	733	200	19	0,5	1571	2800	1,31
6	268	5,5	7	734	275	17,5	1,2	1589	2278	1,37
7	274	5,25	7,7	733	278	16,5	1,1	2041	1972	1,99
8	273	11,3	9,6	770	219	17	1,1	1479	2642	1,27
9	278	20,6	6,3	655	126	19,5	1,1	1466	3222	0,86
10	290	27,6	8,9	666	122	19	0,9	1484	2642	0,67
11	267	11,6	9,4	755	210	17	1,2	2033	2538	1,91
12	272	20,8	6,5	693	119	20	1,0	1592	3094	0,77
13	292	27,5	8,2	711	116	17,5	1,0	1484	2682	0,75
R_{1-5}	0,45	-0,98	0,68	0,63	0,97	-0,89	0,25	0,85	-0,85	
R_{6-13}	-0,66	-0,85	0,28	0,71	0,85	-0,77	0,82	0,89	-0,72	
R_Σ	-0,32	-0,85	0,31	0,59	0,82	-0,76	0,35	0,89	-0,73	
Correlation coefficient (with bending strength)										

The next two columns represent the results of the experiment according to the fig. 1 diagram. The first column F_{n10} - is the maximum indentation force when the 10 degrees conical indenter is on. The second column F_{n90} – is the maximum indentation force when the indenter is 90 degrees 1 mm thickness plate.

The following three columns represent experiment according to the fig. 4 diagram with the 120 degrees conical indenter. F_{1max} – first impact maximum force, T1 – first impact duration, h_∞ - settled indentation depth.

The following two columns represent the results of two non-destructive testing velocity of ultrasonic Lamb waves and impact duration.

Bending strengths σ are listed in the last column.

Correlation coefficients between the measured parameter and the bending strength are listed at the very bottom of the table. Correlation coefficients of the first manufacturer's softboards (R_{1-5}), the second manufacturer's softboards (R_{6-13}) and the overall correlation coefficients (R_Σ) are listed separately in the three rows. Out of that data it is clear that correlation between indentation force F and the bending strength is rather high. Especially high correlation is found between the 120 degrees indenter first impact maximum force and the bending strength. High correlation is observed using non-destructive test – between v and T and the bending strength.

5. CONCLUSION

The obtained results prove the potential of the analyzed methods for softboard bending strength evaluation. It is possible to develop portable devices for fast control of bending strength. Also, it should be mentioned that more investigation should be done to obtain reliable statistical data.

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