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Investigation of the quality of the surface of wood lamellas using air – coupled ultrasonic technique

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Abstract

The investigation of roughness and presence of surface defects in wooden lamellas, which are used in manufacturing of glued wood panels, is an important industrial problem. Well prepared and defect free surfaces guarantee qualitative jointing of the panels. Air – coupled ultrasonic is a very attractive technique for investigation of surfaces of wooden products, because it allows to perform measurements without liquid or semi liquid coupling material. Experimental investigations of wooden lamellas were carried out using focussed dual element and planar air coupled ultrasonic transducers operating in a pitch – catch mode. Experimentally obtained signals are presented in terms of peak to peak amplitude and time of flight.

Keywords: Air – coupled ultrasonics, surface defects, wooden lamellas.

Introduction

Glued wood panels represent an economical use of available timber. With increased demand for lumber, the amount of solid timber is steadily declined. Roughness of the surface of individual lamella used in manufacturing of glued wood panels is not only cosmetic issue, but it can guarantee an economical, perfect panel joint. Inspection of individual lamellas should be carried out after planning process before gluing them to a panel. Our main object of investigation was wooden lamellas which are being used in manufacturing of glued wood panels.

Wood testing method can be chosen accordingly to which major category of wood and wood composites it belongs [1]: standing tree, solid wood (poles, lumber and timber), laminates and wood composites. There are different techniques for investigation of the wood samples: ultrasonic, thermography, radiography, etc. [2-8].

Ultrasonic techniques possess a great potential for investigation of wooden products. Ultrasonic techniques allow monitoring moisture content, presence of cracks, disbonds between glued parts. Different types of ultrasonic waves can be used for wood investigations, but the most common are longitudinal waves. Conventional ultrasonic technique requires liquid or semi liquid coupling materials between ultrasonic transducer and the sample under test, but wetting of wood lamellas with liquid couplants is unacceptable or even not allowed. Air – coupled ultrasonic technique is very attractive for investigation of the wood samples, because it avoids disadvantages caused by couplants [9-11]. Another advantage of air – coupled ultrasonics is higher sensitivity to surface roughness due to the small length of the ultrasonic wave in air at the same frequency in comparison to the wavelength in water.

Test samples

Photos of the wooden lamellas samples which were investigated are presented in Fig. 1. These test samples contain different surface defects:

- non – plane area due to the outer bark (Fig. 1a);
- crack (Fig. 1a);
- non – plane area due to the defective cutting (Fig. 1b);
- non – smooth area due to vibrations of the plane (Fig 1b);
- non – plane area due to the bending of the board (Fig. 1c).

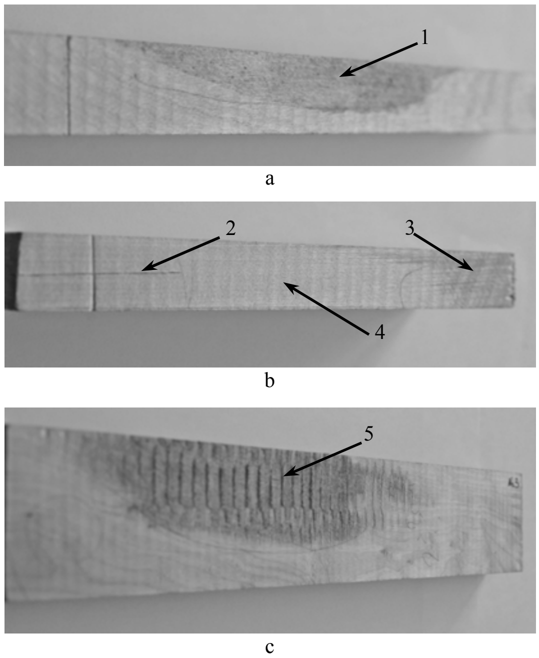

Fig. 1. **Test samples of wooden lamellas with different defects: 1 – non – plane area due to the outer bark; 2 – crack; 3 – non – plane area due to the defective cutting; 4 – non – smooth area due to vibrations of the plane; 5 – non – plane area do to the bending of the board.**

Experimental setup

The experimental investigations of the surfaces of the wooden lamellas were performed using the air – coupled ultrasonic measurement system, which has been developed and manufactured at Ultrasound Institute of Kaunas University of Technology (UI KUT). Experimental investigations were carried out using two types of air –

coupled ultrasonic transducers: the focussed 1 MHz piezocomposite dual element transducer (UI KUT) and a pair of planar 200 kHz transducers (UI KUT) with impedance matching layers.

The structure diagram of the experimental system with the dual element focussed 1 MHz air – coupled ultrasonic transducer operating in a pitch – catch mode is presented in Fig. 2a.

The ultrasonic measurement system consists of a high voltage generator, low noise amplifiers and an analogue to digital converter. The obtained signals are collected and stored in the PC via USB2 bus for further processing. Positioning of the ultrasonic transducers has been performed by a precise mechanical scanning unit. The scanning system was designed in such a way that the test sample is at the fixed position and the ultrasonic transducer is moved during scanning process with steps 0.5 mm in x and y directions.

Use of a dual element transducer allows avoid overlapping of excitation and reflected signals. The transducer was focussed initially to the non defective surface of the wood test sample. The transmitter was driven by the 10 periods and 100 V amplitude burst. The total gain of the measurement system was 35 dB.

Structure diagram of the experimental system with a pair of planar 200 kHz air – coupled ultrasonic transducers operating in a pitch – catch configuration is presented in Fig. 2b.

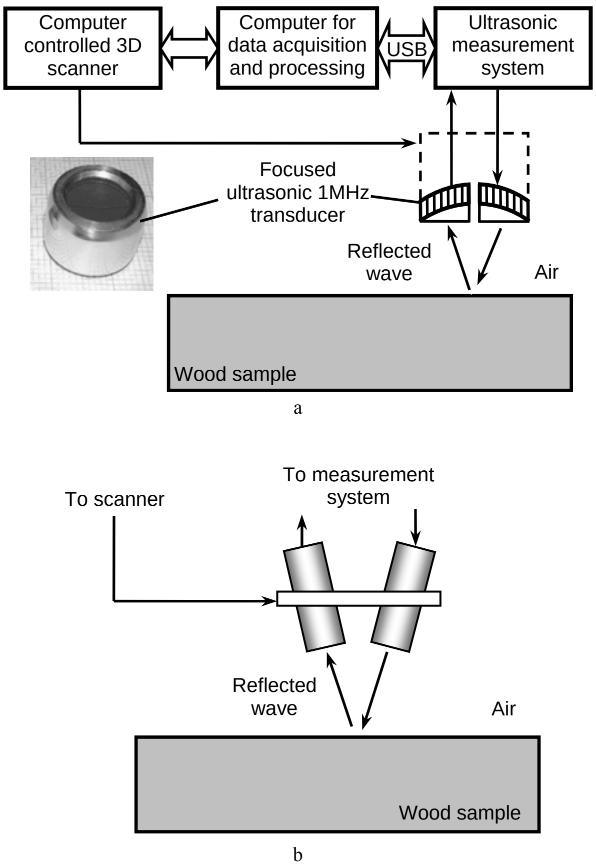

Fig. 2. **Structure diagram of the experimental systems using focussed air – coupled 1 MHz dual element ultrasonic transducer (a) and a pair of planar 200 kHz transducers working in pitch – catch mode (b)**

In order to increase sensitivity of the transducers two matching layers between piezoelectric ceramic and surrounding air are used. The first is made from fibreglass, the second – from balsa wood. The transmission losses of the transducers were 50 dB

The transmitter was driven by the 3 periods and 50 V amplitude radio pulse. The total gain of the measurement system was 27 dB. The measurements were performed with the spatial scanning steps of 5 mm in x and y directions.

Precise profiling of the wooden lamellas using focussed air – coupled ultrasonic transducers

In order to obtain precise measurement results of a profile of the test samples, measurements were carried out using the focussed air – coupled ultrasonic transducers.

The typical ultrasonic signals received in defect free and defective areas of the test sample using focused dual element air – coupled ultrasonic transducers are presented in Fig. 3.

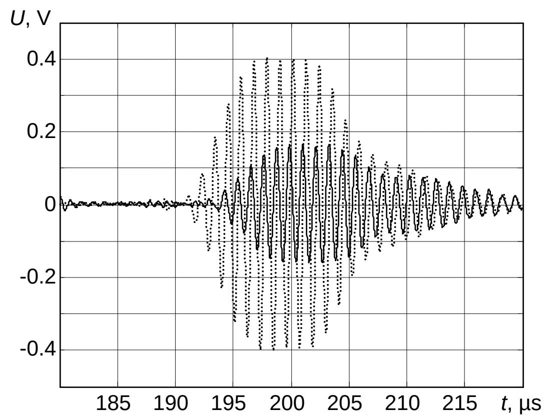

Fig. 3. **Typical signals obtained in a defect free (dotted line) and defective areas (solid line) of the test sample using 1 MHz focussed dual element transducers acting in a pitch - catch mode**

Many wave parameters can be measured, for example, the time of flight, amplitude of the signals, frequency spectra of the waveform, etc. In our case main parameters which allow to detect presence of the surface defects are the amplitude and the time of flight of the ultrasonic pulse. Difference of times of flight of the ultrasonic signals in defect free and defective areas can be found using a cross – correlation function:

$$\Delta t = t\Big|_{\mathrm{CCF}(y_i, y_{ref})=\max}, \qquad (1)$$

where CCF is the cross – correlation function, y_i are the experimentally obtained signals, i is the number of appropriate signal, y_{ref} is the reference signal. After determination of cross – correlation function maximum, a zero crossing procedure with interpolation was applied for more accurate estimation of difference of the times of flight [12].

The results of investigation of the test sample with defects caused by vibrations of the planing device (Fig.1, defect No. 4) are presented in Fig. 4. Fig. 4a shows the amplitude C–scan image obtained from the peak to peak values of individual signals. Periodical changes of the profile height are clearly seen. However, the amplitude C–scan image provides better qualitative evaluation. In order to obtain a quantitative surface height information, the times of flight of the ultrasonic signals were calculated using the cross – correlation in each scanning step. The signal at the first scanning step was taken as a reference. The 3D representation of the time of flight image is presented in Fig. 4b. Changes of the profile height according to the value of the first element in a data array obtained during scanning process can be calculated by:

$$\Delta z = c_{air} \cdot \left(\tau_{ref} - \tau_i\right) / 2 , \qquad (2)$$

where c_{air} is the speed of sound in air (340 m/s), τ_{ref} is the time of flight of the reference signal, τ_i is time of flight of the i – th signal in the C - scan array. The calculated changes of the profile height are presented in Fig. 4c. The obtained results show that profile height changes within ±0,05 mm. A negative trend of the obtained results is clearly seen as well. This trend is due to changes of overall thickness of the test sample. The comparative measurements along x axis of the sample were carried out using a contact micrometer. The obtained maximum values of the profile height deviations are close to ±0,05 mm. They correspond very well to the results obtained using the air – coupled ultrasonic technique.

The results of experimental investigation of the test sample with a defect caused by bending of the board are presented in Fig. 5. The amplitude C – scan image of the

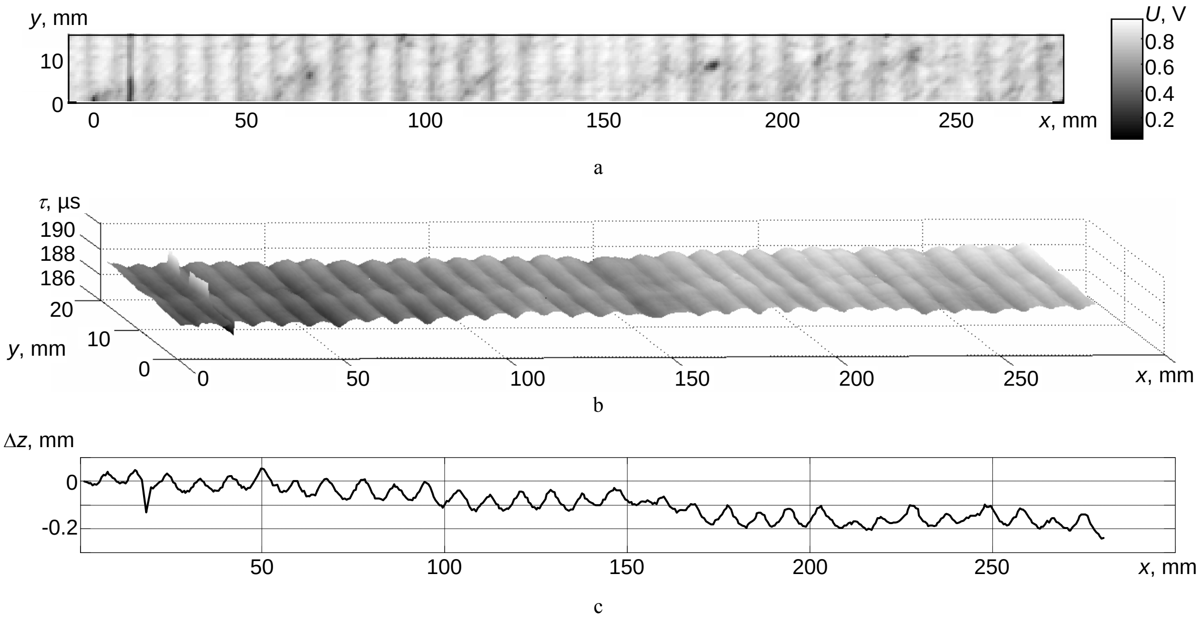

Fig.4. **Experimental results of investigation using focused air – coupled transducers of the test sample with defects caused by vibration of planning device: a – amplitude C – scan image; b – time of flight image (3D representation); c – surface profile of the test sample (Δz axis is zoomed)**

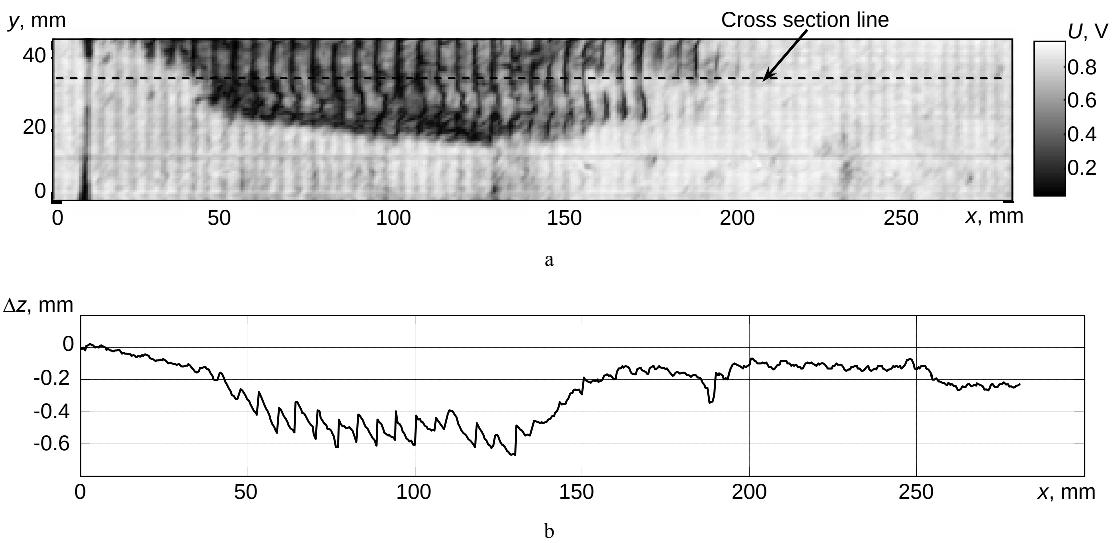

Fig.5. **Experimental results of investigation using focused air – coupled transducers of the test sample with defects caused by bending of the lamella: a – amplitude C – scan image; b – surface profile of the test sample at the cross section line (Δz axis is zoomed)**

test sample is shown in Fig. 5a. Changes of the profile height, calculated using Eq. 1 and 2 are presented in Fig. 5b. The results shows that the air – coupled ultrasonic technique combined with focussed transducers c an be used for visualization of surface defects.

Fast profiling of the wooden lamellas using planar air – coupled ultrasonic transducers

Using focussed air – coupled ultrasonic transducers very good measurement results were obtained. However, this technique is time consuming and not always can be used in industrial applications, especially in fast – moving lines. In order to achieve higher measurement scanning speed the step can be increased. However, increasing scanning step serious defects can be missed. In such a case planar air – coupled ultrasonic transducers with a bigger diameter and bigger overlapping area of the test sample can be used.

Typical signals obtained in defect free and defective areas of the surface of the wooden lamella using the 200 kHz planar air coupled ultrasonic transducers operating in a pitch – catch mode are shown in Fig. 6.

As well as in the case of experimental investigation using focussed transducer the signals are analysed in terms of the time of flight and amplitude of the signal.

The results of experimental investigation of the test sample with a surface defect caused by bending of the board (Fig. 1c defect No 5) are shown in Fig. 7. The defect structure (Fig. 7a) is not so clear like in a case of experiments with focussed transducers, but the defect zone is still visible and detectable using an ordinary amplitude detector. The 3D representation of the time of flight of the ultrasonic waves, which has been calculated using Eq. 1, is presented in Fig. 7b. The calculated change of the profile height is presented in Fig. 7c. The results clearly show the zone of the defective surface. These results are close enough to the results obtained using focussed transducers.

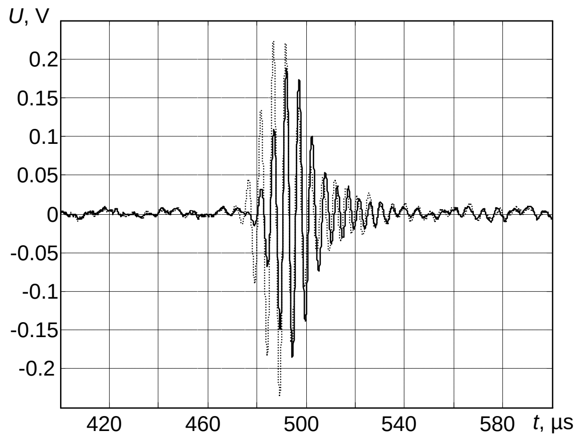

Fig. 6. **Waveforms of the typical signals obtained in defect free (dotted line) and defective areas (solid line) of the test sample using a pair of planar 200 kHz air – coupled ultrasonic transducers operating in a pitch – catch mode.**

Conclusions

For investigation of surfaces of wooden lamellas non contact air – coupled ultrasonic technique was selected.

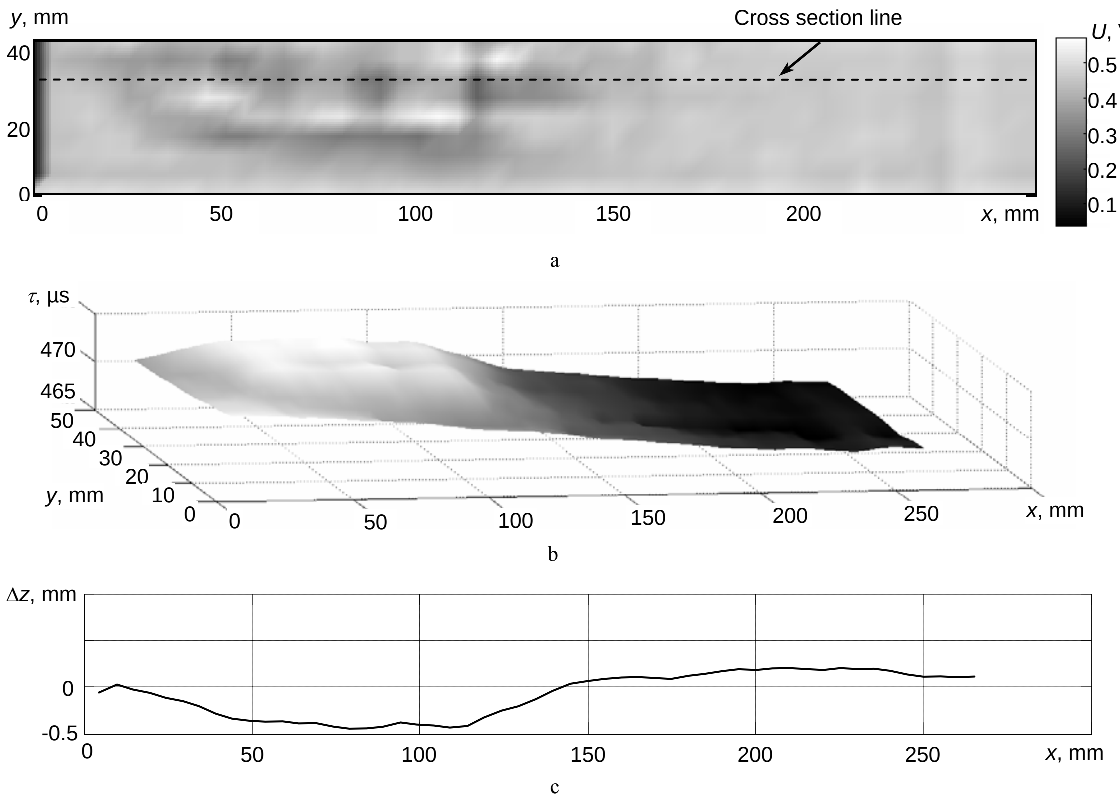

Fig.7. **Experimental results of investigation using planar air – coupled transducers of the test sample with defects caused by bending of the board: a – amplitude C – scan image; b – the time of flight image (3D representation); c – surface profile of the test sample (Δz axis is zoomed)**

Experimental investigations were carried out using single spherically focussed dual element transducer and a pair of planar ultrasonic transducers operating in a pitch – catch mode.

The experimentally obtained results showed that the changes of the profile height smaller than 0,1 mm can be detected using focussed air – coupled ultrasonic transducers. In order to determine minimal changes of the profile height which can be registered it is necessary to perform additional experiments.

In order to achieve faster scanning speed planar ultrasonic transducers can be used. Experimental investigation of lamella with a defect caused by bending of the board shows that results obtained with focussed and planar transducers are close enough.

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Medinių tašelių paviršiaus kokybės tyrimas ultragarsiniu nekontaktiniu metodu per oro tarpą

Reziumė

Medinių tašelių, naudojamų klijuotų medžio plokščių gamyboje, paviršiaus šiurkštumo ir defektų buvimo tyrimas yra aktuali pramonės problema. Gerai paruošti tašelių paviršiai leidžia plokštes kokybiškai suklijuoti. Nekontaktinis ultragarsinis metodas yra patrauklus medžio gaminiams tirti tuo, kad įgalina atlikti tyrimus nenaudojant skysčių akustiniam kontaktui užtikrinti. Eksperimentiniai medinių tašelių tyrimai atlikti naudojant fokusuotąjį dviejų elementų ir plokščiuosius ultragarsinius keitiklius, veikiančius atspindžio nuo paviršiaus rėžimu. Eksperimentiškai gauti signalų masyvai pateikiami maksimalios amplitudės ir signalo sklidimo laiko aspektais.

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