NDT TESTING OF CELLULOSE FIBER CEMENT BOARDS USING NON-CONTACT ULTRASOUND

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Abstract

This paper presents experimental studies of cellulose fiber cement boards using non-contact ultrasonic system were performed. Both the theoretical and experimental studies were performed on cellulose fiber cement boards. Cellulose fiber cement boards are the materials commonly used in architectural engineering for many external and internal applications such as buildings elevation or as walls and roofs covering materials. The theoretical studies of plate waves served to identification of the wave mode measured in the boards. It was found that the flexural (A0) mode, having velocity about 1200 m/s, propagates in the material. The preliminary experiments were done for the cement boards specimens, using 3D laboratory non-contact ultrasonic system and then, based on the obtained results new dedicated 1D scanner was designed and built. The obtained results confirmed applicability of the non-contact ultrasonic method using plate waves to studies of cellulose fiber cement boards. It allowed distinguishing between healthy and defective area within the boards and thus the method can be found as promising tool for future factory production control.

Key words: acoustic methods, non-contact ultrasound, nondestructive testing, cellulose fiber cement boards

1. Introduction

Cellulose fiber cement boards are the materials commonly used in architectural engineering for many external and internal applications such as buildings elevation or as walls and roofs covering materials [1, 2]. Modern boards are asbestos-free and are classified as eco-friendly constructional materials. They are characterized by good fire-proof and heat insulation as well as moisture-proof performance. Moreover, they are easy for construction, light weight, they have stable dimensions durability and long service life.

Accordingly to the polish norm [2], the manufacturer of the cellulose fiber cement boards, which are used in architectural engineering, is obliged to organize engineering inspection department in the factory, responsible to regular control of products. The factory production control process is based on studies of repeatability of geometrical parameters, apparent density, leak test, vapor permeability test and standard mechanical bending strength testing [2].
The main disadvantage of most of the standard inspection methods, specified by polish norms [2, 3, 4] is their selective (the size of testes specimens is much smaller than the size of the whole element) and destructive character. The abovementioned limitations can be significantly reduced by application of complementary, non-destructive tests e.g. using ultrasonic methods, which are recognized as a powerful tool widely applied tool in NDT community. The main purpose of the paper is to evaluate the applicability of the non-contact ultrasonic method to study of the cellulose fiber cement boards during their production. The paper is focused on both theoretical and experimental studies of the plate wave propagation phenomena in the material. Within theoretical framework the analysis of the Lamb waves (A0 – asymmetric zero mode) was performed, which was found to be the most convenient to diagnose the quality of the cellulose fiber cement boards. The preliminary experiments were done for the cement boards specimens, using 3D laboratory non-contact ultrasonic system and then, based on the obtained results new dedicated 1D scanner was designed and built.

2. Ultrasonic studies

2.1. Theoretical studies

Lamb waves (also called plate waves) can be generated in a plate with free boundaries with an infinite number of modes for both symmetric and antisymmetric displacements within the layer, [11]. The symmetric modes are also called longitudinal because the average displacement over the thickness of the plate or layer is in the longitudinal direction. The antisymmetric modes exhibit average displacement in the transverse direction and also called flexural modes. The Rayleigh-Lamb frequency equations for both modes, describing the dispersion of phase velocity can be written as, [11]:

\[
\frac{\tan(qh)}{\tan(ph)} = -\frac{4k^2 pq}{(q^2 - k^2)^2} \quad \text{for symmetric modes},
\]

\[
\frac{\tan(qh)}{\tan(ph)} = -\frac{(q^2 - k^2)^2}{4k^2 pq} \quad \text{for antisymmetric modes},
\]

where \( p \) and \( q \) are given by:

\[
p^2 = \left(\frac{\omega}{c_L}\right)^2 - k^2 \quad \text{and} \quad q^2 = \left(\frac{\omega}{c_T}\right)^2 - k^2.
\]

In the expression (1) and (2) the quantity \( h=d/2 \), where \( d \) is the board thickness, \( c_L \) and \( c_T \) are longitudinal and shear wave velocities of the plate, respectively. The wavenumber \( k \) is equal to \( \omega/c_P \), where \( c_P \) is the phase velocity of the Lamb wave mode and \( \omega \) is the circular frequency. Fig. 1 plots the calculated dispersion curves, calculated as a solution of the equation (2), for cellulose fiber cement board are presented. The numerical values of the material properties used for calculations are listed in Table 1.

It is visible in Fig.1 that the cut-off frequencies of the first symmetric mode (S1) is 0.25 MHz, while anti-symmetric mode (A1) is 0.2 MHz. Considering the range of fre-
quencies used in experiments (50-150 kHz), theoretical results give information that in the cement boards only S0 and A0 modes can exist.

Fig. 1. Calculated dispersion curves for a cellulose fiber cement board.

Table 1. Material properties of cellulose fiber cement board

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, $\rho$ (g/cm$^3$)</td>
<td>1.6</td>
</tr>
<tr>
<td>Longitudinal wave velocity, $c_L$ (m/s)</td>
<td>2630</td>
</tr>
<tr>
<td>Shear wave velocity, $c_T$ (m/s)</td>
<td>1446</td>
</tr>
<tr>
<td>Board thickness, $d$ (cm)</td>
<td>7.8</td>
</tr>
</tbody>
</table>

2.2. Experiments

Ultrasonic studies of the cellulose fiber cement boards were performed using non-contact ultrasonic system. Prior to the pivotal tests the preliminary theoretical and numerical studies were performed aiming at selection of optimal experimental conditions such as frequency, shape of generated impulse, distance between transducers and board. The tests allowed also to evaluate which of considered wave modes (longitudinal wave, surface wave, Lamb wave) is the most effective from the point of view of transmitted energy. Moreover, such studies have given possibility to understand if, how and which of the material properties influence on the measured wave parameters. Results of simulation studies yielded the qualitative evaluation of the role of the defects geometry (shape, size) on measured signals and estimation of the role of local inhomogeneity of the material on wave parameters.

The laboratory version of non-contact 3D ultrasonic scanner is shown in Fig.2. The device allow to studies of materials using various methods: in transmission or echo...
mode, using wave reflectometry as well as spectroscopy of surface waves. Preliminary tests were performed on the device on the specimens of various sizes (obtained from the whole board) in order to estimate maximal dimensions of the boards for which the signal to noise ratio is high enough to be acceptable.

![Fig.2. Photography of laboratory non-contact ultrasonic scanner.](image)

Following the results of preliminary tests, the Lamb waves operating at 50 and 100 kHz frequency were chosen as the most effective to study the material and the simplified version of 1D non-contact ultrasonic scanner was built (see Fig. 3b).

The studies were performed on the cellulose fiber cement boards using Lamb waves propagating along the surface of the materials. In the Fig. 3a scheme of experimental configuration for Lamb wave composed of a pair of transducers, having 50 and 100 kHz center frequency (ULTRAN Group). The transducers were exited (by arbitrary generator) using the linear chirp (signal for which the instantaneous frequency varies linearly with time within the certain bandwidth) having the frequency range fitted to their bandwidth. The waveforms were recorded by digital oscilloscope at 10 MHz frequency rate. The signal generation and reception was done by a professional computer controlled measuring instrument Handyscope HS3 (TiePie engineering) via USB. Moreover, the system was equipped in stepper motor and feed rollers to move the board along line.
3. Results and analysis

In Fig. 4 and Fig. 5 exemplary results of studies obtained by non-contact ultrasonic scanner are presented. The Fig. 4 presents the B-scan of the whole cellulose fiber cement boards in linear (left) and logarithmic (right) scale. In the Fig. 5 the partial B-scan of the board, focused on cracked part of the cement board is presented.

Fig. 4. B-scan in of the of the whole cellulose fiber cement boards in linear and logarithmic scale (vertical axis – boards length [mm], horizontal axis - samples, colorbar – signal amplitude

Fig. 3 Scheme of experimental configuration for non-contact ultrasonic tests using Lamb waves (a) and photography of experimental setup to study of the cellulose fiber cement boards (b)
The results presented in the Fig. 4 and 5 concern the A0 mode, which was identified considering theoretical predictions (velocity about 1200 m/s @ 100 kHz) and then confirmed in ultrasonic experiments. Analysis of the B-scans allows distinguishing between healthy and defective area. In the case of results for the board presented in the Fig.5 it was possible to identify visually the type of defect – delamination. However, in general the source of the changes of amplitude of the signal may be different. For example it is not known how the local thickness changes or local inhomogeneity of the material, being result of complex procedures of production of the cement boards, influence on the signal parameters.

4. Conclusions

In the paper experimental studies of cellulose fiber cement boards using non-contact ultrasonic system were performed. The main purpose was to evaluate of the applicability of the method to study of the boards during their production. Therefore, in order to find optimal experimental conditions the first phase the studies were focused on laboratory tests using 3D non-contact ultrasonic scanner on the board specimens (of smaller size). Then, new 1D scanner working with Lamb (or surface) waves was designed and made.

Both the theoretical and experimental studies were performed on cellulose fiber cement boards. The theoretical studies of plate waves served to identification of the
wave mode measured in the boards. It was found that the flexural (A0) mode, having velocity about 1200 m/s, propagates in the material.

The obtained results confirmed applicability of the non-contact ultrasonic method using plate waves to studies of cellulose fiber cement boards. It allowed distinguishing between healthy and defective area within the boards and thus the method can be found as promising tool for future factory production control. However, the further studies, for larger group of representative materials are necessary in order to verify and optimize its efficacy.

In the paper only the amplitudes of transmitted Lamb waves as a function of position within the plate were analyzed. In general the sources of the changes of amplitude of the signal may be different. For example it is not known how the local thickness changes or local inhomogeneity of the material, being result of complex procedures of production of the cement boards, influence on the signal parameters. Therefore, one of the directions of the future studies will be focused on identification of the material defects (cracks, delamination etc.) or their geometry, while the second direction should be focused on studies of effective descriptors of the defects in the material. It can be achieved by application of simulation of wave propagation phenomena, where the defects can be directly introduced into the model and by development of the advanced signal processing methods for effective extraction of the information from transmitted signals.

References
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