EXPERIMENTAL STUDY OF THE ULTRASONIC WAVE PROPAGATION IN MATERIALS WITH MECHANICAL STRESSES*

Y. IVANOVA,
Institute of Mechanics-BAS,Sofia,Bulgaria
e-mail: yonka@imbm.bas.bg

T. PARTALIN,
Sofia University, Faculty of Mathematics and Informatics,
5 James Baucher Bld., Sofia, Bulgaria
e-mail: topart@fmi.uni-sofia.bg

M. MIHOVSKI,
Institute of Mechanics-BAS,Sofia,Bulgaria
e-mail: nntdd@imbm.bas.bg

ABSTRACT. The present paper deals with acoustoelasticity in stressed and elastically deformed metal materials during the bending loads. The dependence of ultrasonic wave's parameters on the stress state in materials is studied. An experimental evaluation of the velocity and change of surface ultrasonic pulse as a function of bending loads is described.

KEY WORDS: ultrasonic surface wave, velocity, mechanical stress

1. Introduction

In the papers [1,2] the possibilities of application of ultrasonic surface waves for the evaluation of mechanical stresses are studied. The experiments are carried out on the metal sheet with a tension gradient both traversal and longitudinal. That formulation makes the results difficult to compare and assess. To find quantitative interrelations between the parameters of the stress state of the material and those of surface ultrasonic waves one needs a model, that takes into account only the transversal stress gradient.

A variable-section beam with the same strength along with bending is considered in the present work. The propagation of ultrasonic surface waves in bent

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metal beam is evaluated dependent on the stresses and taking into account the ratio \(\frac{\lambda}{h}\) (where \(\lambda\) is ultrasonic waves length and \(h\) is height of metal sample).

The metal sample, made from low carbon steel, is loaded with bending force \(P\) under the scheme shown in Figure 1. The principal stress \(\sigma\) is determined by the formula [3]

\[
\frac{M_y(x)}{W_y(x)} = \sigma < \sigma_y,
\]

where \(M_y\) is a bending moment toward axis \(y\), \(W_y\) is a resistance moment, \(\sigma_y\) is a yield stress. Mechanical stresses are equal to the length of along the metal sheets from the place of attachment to the point of force application. The maximum value is determined by relations (1.2) [3,4].

\[
\sigma = \frac{M_y}{J_y} z_1 = \frac{M_y}{J_y} z_2 = \frac{M_y}{W_y} = \frac{6Pl}{b(x)h^2}
\]

where \(l\) is the length of the metal beam, \(J_y\) is a inertia moment of the section around the neutral axis \(y\), \(z_1\) and \(z_2\) are the \(z\) coordinates of the upper and lower surfaces of the beam [3]. After substitution of the expression

\[
b(x) = 2xtg \frac{\alpha}{2} = 2k
\]

where \(\alpha\) is the angle at the apex of the triangular beam \((tg \frac{\alpha}{2} = k)\) and \(x = l\) we obtain expression for the mechanical stresses

\[
\sigma = \frac{3P}{h^2k}
\]

The part above the zero line \((n)\) of the bent beam is subjected to tension and the part below - to compression. Maximum stress is defined by (1.4) within the approximations accepted in [3].

### Table 1. Experimental samples

<table>
<thead>
<tr>
<th>N</th>
<th>(L, \text{m})</th>
<th>(B, \text{m})</th>
<th>(\alpha)</th>
<th>(k = tg\alpha / 2)</th>
<th>(h, \text{m})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.4142</td>
<td>45°</td>
<td>0.4142</td>
<td>0.005</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>0.4142</td>
<td>45°</td>
<td>0.4142</td>
<td>0.006</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>0.4142</td>
<td>45°</td>
<td>0.4142</td>
<td>0.008</td>
</tr>
<tr>
<td>4</td>
<td>0.5</td>
<td>0.4142</td>
<td>45°</td>
<td>0.4142</td>
<td>0.01</td>
</tr>
</tbody>
</table>

### 2. Ultrasonic investigations

An experimental setup for ultrasonic studies is shown in Fig. 2. A computerized ultrasonic instrument produced of Optel company [8] is used for that
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purpose. It consists of a generator and receiver of ultrasonic waves OPGUD, and an ultrasonic card, integrated within a PC, class Pentium III. The ultrasonic instrument has a block for measuring the time of ultrasonic impulse propagation with accuracy up to 1 ns. The equipment has 8 bits resolution and sampling rate of 100 MHz. To attain a higher accuracy of measurement, we undertake measures for maintaining constant conditions for the generation of acoustic signals, and we use one and the same liquids.

3. Experimental results

Surface “Rayleigh” ultrasonic waves are excited by an angular transducer with variable angle, at an angle of refraction close to the second critical one of a system plexiglass-steel. The working frequencies of the ultrasonic impulses are 2 and 4 MHz. The penetration depth of surface wave is of $1-1.5 \frac{\lambda}{R}$ order, where $\lambda$ is wave length [5]. The wave lengths are approximately equal to 0.75 mm for frequency 4 MHz and 1.5 mm for 2 MHz.

Using a through transmission technique, we register and record in digital form echo-signals emitted from emitting transducer (E) and received by receiver (R) from the top side of the sample. The receiving transducer moves along the specimen length covering distance $\Delta L$.

Velocities of surface waves are measured for metal beams with varying thickness $h$ (Table 1) and loads till 500N, according to preliminary calculated stresses. Procedure for determining the velocity is presented in detail in [1, 6, 7].
Velocity of the surface wave \((C_R)\) is estimated following (3.1) and measured as shown in the figure 2.

\[
(3.1) \quad C_R = \frac{2(L_2 - L_1)}{(\tau_2 - \tau_1)} = \frac{\Delta L}{\Delta \tau},
\]

Where \(\Delta L\) is the distance between position (1) and (2) of the receiver, and \(\tau_1\) and \(\tau_2\) are transit times of the wave obtained at distances \(L_1\) and \(L_2\).

Measurements of the velocity in different directions without load shows anisotropy of the material. The anisotropy is appraised as a relative change in velocities in directions from 0 to 90 ° toward the x axis, as shown in Figure 3a. Fig.3b gives a change of velocities that are measured in different directions under loads. Anisotropy does not change vastly the influence of the stress on the propagation of ultrasonic wave, but obviously needs more studies.

Relative change of the surface wave’s velocity under stress is determined by the formula:

\[
(3.2) \quad dC_R = (C_{R_0} - C_R) / C_{R_0}.
\]
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where $C_R$ and $C_{R_s}$ are the velocities in stressed and unstressed sample. The experiments are carried out under the same conditions and temperature.

![Graph](image1)

**Fig.4.** The dependence $dC-R\times\sigma$

![Graph](image2)

**Fig.5a**

Fig.5 Signals before and after loading of the samples 1 and 3

**Fig.5a**) Signals before ($P=0\ N$) and after loading ($P=205\ N$) of the sample 1

**Fig.5 b**) Signals before and after loading ($P=500\ N$) of the sample 3
Fig. 4 shows the dependence of the relative changes $dCR$ on the stresses, obtained at 4 MHz (a) and 2 MHz (b) at different ratio $\lambda/h$. Fig. 5 shows signals from ultrasonic surface waves before and after loading for samples 1 (a) and 3 (b). The signals at bending loads appeared earlier than those signals received from unloaded sample and change their shapes and lengths.

The presence of a stress gradient leads to a change of shape and spectrum of the pulse wave [2]. Analysis of the dependence on the stress gradient is a complex task, which requires future investigation.

4. Conclusion
The influence of stress gradient on the shape and phases of ultrasonic pulses is visible. The dependence of the relative changes $dC_R$ on the stresses is obtained at frequencies 2 and 4 MHz.

The results show the applicability of ultrasonic technique for evaluation of the tension gradient in materials with low anisotropy such as rolled structural steel. Knowing about the inaccuracy of traditional methods for stressed state assessment, the use of ultrasonic waves becomes a very successful method.

REFERENCES