

STRUCTURAL DIAGNOSTICS OF GEOMATERIALS BY LASER ULTRASONIC SPECTROSCOPY

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Abstract

The possibilities of laser ultrasonic echoscopy for detection and diagnostics of rock structural imperfections are considered. It is shown, that calculating with the help of fast Fourier transformation spectra of the signals, arrived in a sample and multiple scattered, and carrying out a corresponding frequency filtration, it is possible to obtain environment reflection factor and on its basis to construct the sample structure image. The examples of forming images of structural changes under different influences on the rock samples are presented. The ferruginous quartzite samples were influenced by pulse electromagnetic field, the Karelian marble samples – thermal field.

Keywords: rock, laser ultrasonic spectroscopy, sample structure visualisation.

1 Introduction

Some problems of geophysics requires the research of structural change of rocks under influence of different physical fields (thermal, mechanical, electromagnetic, etc.) [1]. The electron microscopy and X-ray structural analysis are basic methods for investigation of rock structural. In spite of high sensitivity, resolution and instrument level, the application field of these methods for rock multiple determinations are bounded by laboriousness and self-cost. Therefore the laser ultrasonic reflection method is interested for structural diagnostics of geomaterials [2].

This paper is devoted structural diagnostics of rock sample under electromagnetic and thermal influences by the laser ultrasonic spectroscopy.

2 Experimental setup

The laser optoacoustic transducer with indirect registration of wideband ultrasonic pulses (fig.1) was used for ultrasonic testing of rock samples. Laser pulses from the solid Q-switch laser 1 coming through a fibre-optical cable 2 in the optical forming system 3, fixed on the case 4 optoacoustic transducer. The optical system 3 forms a light beam in radius of 2.5 mm, coming to a transparent prism 5 of plexiglas with the plane-parallel bases. Further this prism is used as acoustic duct for acoustic signals.

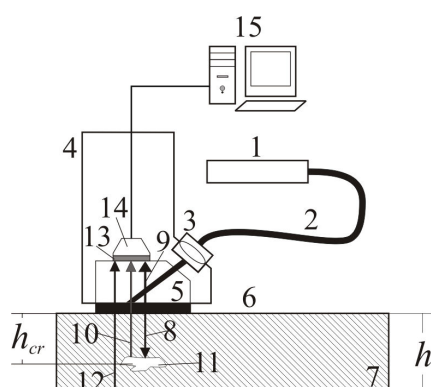


Figure 1 – The scheme of the laser optoacoustic transducer: 1 - the pulse solid laser, 2 - fibre-optical cable, 3 - optical system, 4 - the case of the laser optoacoustic transducer, 5 - transparent prism, 6 - optoacoustic generator, 7 - researched sample, 8 - probing pulse, 9 - reference pulse, 10 - pulse reflected from the defect, 11 - defect of structure of the sample, 12 - pulse reflected from the sample backside, 13 – damper piezo-receiver, 14 - preamplifier, 15 - computer system of data processing.

The plate 6 of black plastic with the thickness of 300 μm which has the acoustic impedance close to the impedance of plexiglas and high value of thermal expansion factor is fasten to the working plane of prism (on which the optical beam falls). This plate also carries out functions of optoacoustic generator. Really, it intensively absorbs falling on it laser radiation, which results in fast local heating of surface area, thermal expansion of this area and, as result, to excitation in a sample of a geomaterial 7 ultrasonic longitudinal elastic wave pulses. Diameter of a ultrasonic beam excited in a sample is equal to diameter of the light beam falling on

The ultrasonic signals extending in a researched sample are considered as probing pulses 8, and extending in a prism 5 - as reference pulses 9.

Reference signals 9, the signals 10 reflected from defect 11, and also the signals 12 reflected from the back sample surface are accepted by damper wideband piezo-receiver 13 and transformed by the last to electric signals which further are amplified by preamplifier 14 and processed by the computer 15.

The spatial extent of probing signal $\Delta l = V_L \Delta \tau_{ref}$ (here $\Delta \tau_{ref}$ - ultrasonic pulse duration) less than 0.5÷0.6 mm. It is allowed to detect the imperfections in material on depths from 0.5 mm.

By the difference of times of the arrival probing signal t_1 and reflected from backside sample pulses t_2 to piezo-receiver, by known value of the sample's thickness h it is possible to determine velocity of longitudinal elastic wave propagation in sample: $V_L = 2h / (t_2 - t_1)$.

The diagnostics of extended defects (for example, microcracks) was carried out by echoscopy with descret scanning at points located along profiles on the sample surface.

The scheme of laser ultrasonic scanning is shown on the figure 2. It is allowed to form the plane image of structural distribution of imperfections in rock sample.

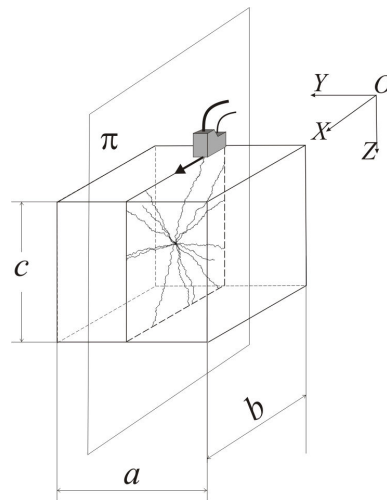


Figure 2 – The laser ultrasonic scanning scheme of the rock sample.

The laser optoacoustic scanner (LOAS) excites powerful wide band ultrasonic pulse at point on sample surface. This pulse propagates along Z axis and partially reflects from imperfections. The reflected signal is received by LOAS piezo-receiver at that point. The signal track contains one-dimensional diagnostic information and we'll call it A-scan. LOAS is moved from point to point along X axis. The ultrasonic irradiation and reception processes are repeated at each point, thereby the A-scans are formed.

Then the reflection coefficient is calculated for each A-scan. Initially the spectra of reference and reflected signals are obtained by Discrete Fourier Transformation. After that each spectral component of reflected signal divides by conformable spectral component of reference signal. So far so the spectra of signals goes to zero in high-frequency region, the significant error appears by the spectral component deviation. For reasonableness of this procedure the spectral ratio corrects by filter:

$$\varphi(f) = \exp(-(f/f_0)^2) - \exp(-(f/f_1)^n), \quad (1)$$

where f_0, f_1, n depends on spectral composition of backward scattered signal by sample.

Consequently the three-dimensional number array is formed. It consists scanning depth (along Z axis or A-scan), scanning point coordinates (along X axis or B-scan) and the signal amplitudes. This array is used for forming structural image. The brightness of image point (color tone) depends on filtered signal amplitude. This image carries the ultrasonic reflection factor information on depth in scanning plane, and, hence, the information of structural imperfections.

3 Experimental results

Let's consider two examples of use of the algorithm described above for rock sample defectoscopy and structural visualization.

In the first case object of research was the Karelian marble sample as a rectangular parallelepiped with the sizes of the sides $x=30, y=26, z=28$ mm. The initial sample structure is presented on figure 3a.

After sample heating to 700 degrees the structure began more homogeneous and the imperfection size has considerably decreased (figure 3b).

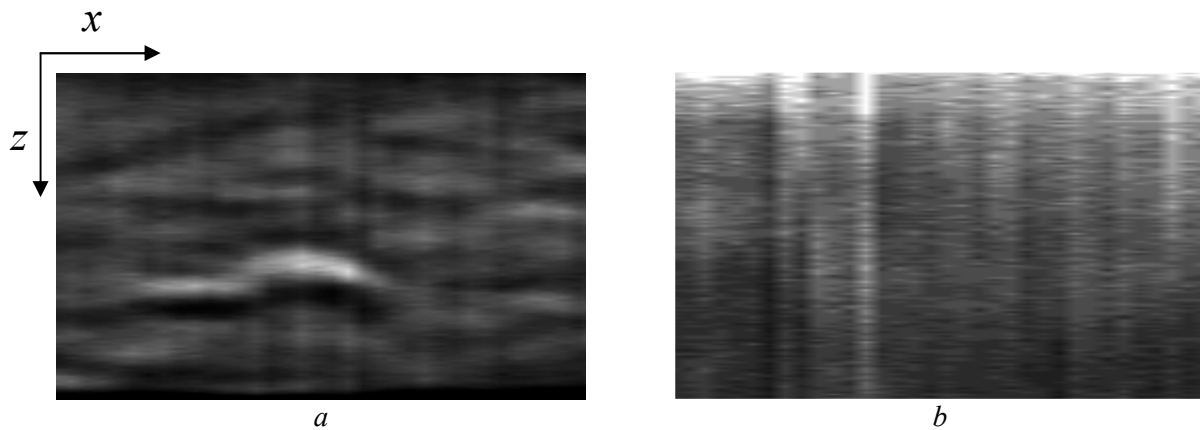


Figure 3 – Laser ultrasonic structural images of Karelian marble sample ($x=30$ mm, $y=26$ mm, $z=28$ mm): *a* – before heating; *b* – after heating to 700°C.

Viewed below second example is called to show the laser ultrasonic spectroscopy possibilities for an estimation of structural changes in the geological objects caused by exterior physical influences. Obtaining of such estimation is necessary for an optimum select of influence types and substantiation of their such modes which provide, for example, selective character of fracture, the greatest efficiency of geomaterial disintegration processes, impairments of connections between their separate components and other effects used at concentration and processing of initial mineral raw material.

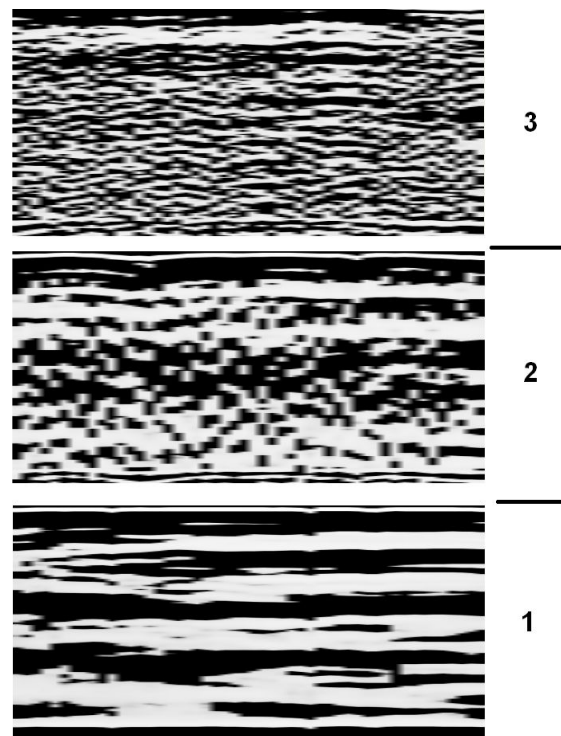


Figure 4 – Laser ultrasonic structural images of ferruginous quartzite sample: 1 - initial condition, 2 - after the first electromagnetic pulse influence (power P_1), 3- after the second electromagnetic pulse influence (power $4P_1$).

The structural changes of ferruginous quartzite samples (thickness about 5 mm, cross area about 10 cm²) are researched by the laser ultrasonic echoscopy and structure visualization. The structural changes are induced by the powerful electromagnetic pulses. Results of these investigations presented on figure 4, where figure 4.1 is the initial structure image of sample, and figure 4.2 and 4.3 are images of sample structural changes after action by electromagnetic pulses of conditional power P_1 and $4P_1$. The size of a sample structural components decreases and the structure becomes more the homogeneous.

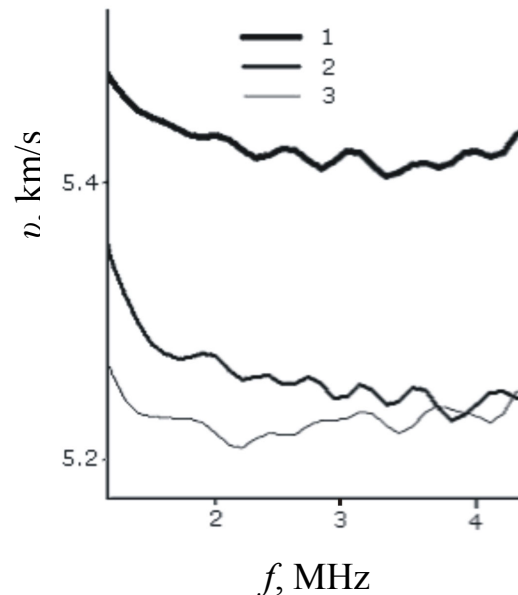


Figure 5 – Frequency dependences of longitudinal wave velocity in ferruginous quartzite sample: 1 - initial condition, 2 - after the first electromagnetic pulse influence (power P_1), 3 - after the second electromagnetic pulse influence (power $4P_1$).

Fracture of ferruginous quartzite sample structure is confirmed by the laser ultrasonic spectroscopy investigations [3], namely: decrease of the longitudinal wave velocity (figure 5) and increase of ultrasonic attenuation factor (figure 6).

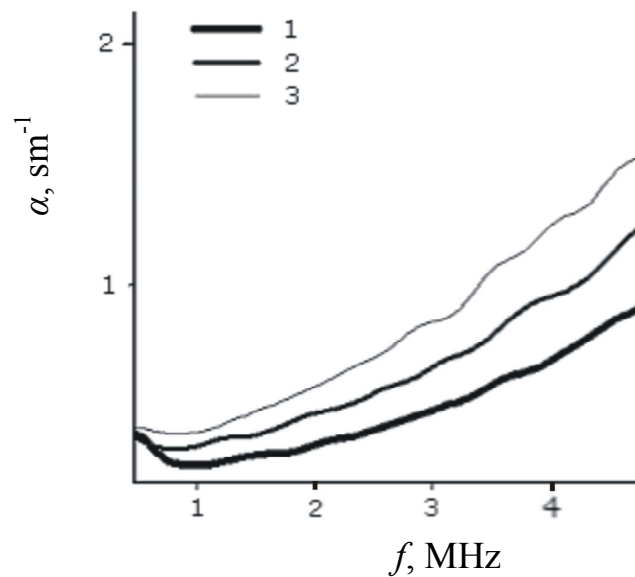


Figure 6 – Frequency dependences of ultrasonic attenuation factor in ferruginous quartzite sample: 1 - initial condition, 2 - after the first electromagnetic pulse influence (power P_1), 3- after the second electromagnetic pulse influence (power $4P_1$).

Within the framework of the present article there is no problem of discussion of essence and the mechanisms occurring at the specified action of structural changes in ferruginous quartzite as the relevant questions rather in detail surveyed by authors of article [4].

4 Conclusions

In summary, the given on figure 3 and 4 rock sample structure images shows, that the laser ultrasonic spectroscopy with visualization of its results can be the effective tool of studying of the induced defects in geomaterials at executing the relevant research works.

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