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Array of EMATs for Detection of Laser-induced Ultrasound

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Abstract
The paper considers detection of laser-induced ultrasound for measurement of the elastic waves velocities and determination of the elastic modulii of the metalic composites. The specimen of semi-cylindrical form is used. The array of electromagnetic acoustic transducers is employed for detection of the elastic pulses at the perimeter of the semi-cylinder.

Keywords: Laser-induced ultrasound, time of flight (TOF), EMAT, metallic composites, velocity, moduli.

1. Introduction

Excitation of laser-induced ultrasound showed their indisputable benefits for the solution of the tasks of non-destructive testing and evaluation demonstrating considerable advantages for frequency bandwidth and as result better spatial resolution in comparison with traditional methods [1]. The detection technique is determinative for ultrasonic pulses registration. All-optical schemes allow to carry out measurements with curved surfaces and under high temperature but require mechanical treatment of the surface. Undoubtedly optical methods possess high potential and are well promising for the industrial applications of non-destructive testing and evaluation. Meantime there are known successive combinations of laser excitation with non-contact detection of ultrasound by means of electromagnetic acoustic transducers. The achieved bandwidth is comparable with optical methods of registrations. The aim of present paper is demonstration of possibilities of multichannel detection of ultrasound, which is induced by focused laser pulse. As a development of composite materials requires methods for measurement velocities and elastic moduli. The direct measurement of the longitudinal and shear pulses in the specimens is well promising for properties evaluation. The elastic moduli of isotropic media can be described by the following expressions:

$$M=\rho v_L^2,\ \ G=\rho v_S^2 \tag{1}$$

here M, G are the longitudinal and shear waves moduli, respectively, ρ – density of material, v_L, v_S are velocities of longitudinal and shear waves. The measured moduli can be used for expression of the Young's moduli and Poisson's ratio.

2. Electromagnetic acoustic transducers

The basic idea of EMAT operation is well described in the literature [2]. The transducers are used in nondestructive testing both for the excitation of the probe pulses as for detection of the scattered ultrasound via switch between operational regimes. The simplest transducer comprises of coil and permanent magnet which magnetizes the specimen. The cylindrical magnet with the outer radius of 25 mm and inner radius of 13 mm was used in our experiments. The magnetic field is about 0.25 T. The combination of EMAT with laser-induced ultrasound allows to separate the excitation regime, which can be carried out by laser radiation, and concentrating on the detection of the ultrasound. Experimental scheme of measurement is rather

simple where the excitation of the ultrasound is carried out from one side of the plate while the detection of ultrasound is from the opposite side by EMAT [3]. In general case laser pulse induces longitudinal, shear and bulk acoustic waves. The directivity of the pulses' intensity depends on the power density and the laser spot on the metallic surface. The feature of the shear pulses directivity is their declined propagation into the bulk of the medium. Thus the direction of shear pulses propagation is not normal to the surface that makes some difficulties for the velocity measurements in the plate via echo measurement.
The specimen form of semi-cylinder can be used for the simple solution for measurements of the shear wave velocity. The sources of ultrasound can be induced by focusing of the laser radiation in short interval by means of cylindrical lens. Thus the bulk waves with cylindrical wavefront are launched in the specimen. The measurement of velocity can be carried out by the array of transducers, which are located at the cylindrical surface of the specimen. The geometry of the samples is constituted by radius and thickness and therefore the traveling distance is fixed and the goal is measurement of arriving time of the pulse.

3. Experimental setup

The laser pulses of about 10 ns duration are under focus of our experiments. The absorption of the laser radiation by thin layer near metallic surface induces heat sources, which diffuse in the bulk of the material. The heat penetration depth is about one micrometer for 10 ns pulses. The heating of the material induces elastic pulses, which spread in to the bulk. The focusing of the laser radiation changes the efficiency of the excitation of surface and bulk waves. The efficiency of excitation of the shear pulses increases while the directivity of the longitudinal waves changes and their maxima are inclined from the normal to the surface. The detection system consists of five electromagnetic acoustic transducers which are located at the cylindrical surface of the specimen. The single transducer consists of induction coil and preamplifier based on the single operational amplifier. The permanent NdFeB magnet placed on the top of the specimen for magnetization of the sample. The transducers are placed on the two layer printed circuit board. The location of transducers allows detection of bulk and surface pulses. The adjustment of the sample position carried out by criterion of equal time delay for similar pulses that proves the source of ultrasound is near the axis of cylindrical surface.

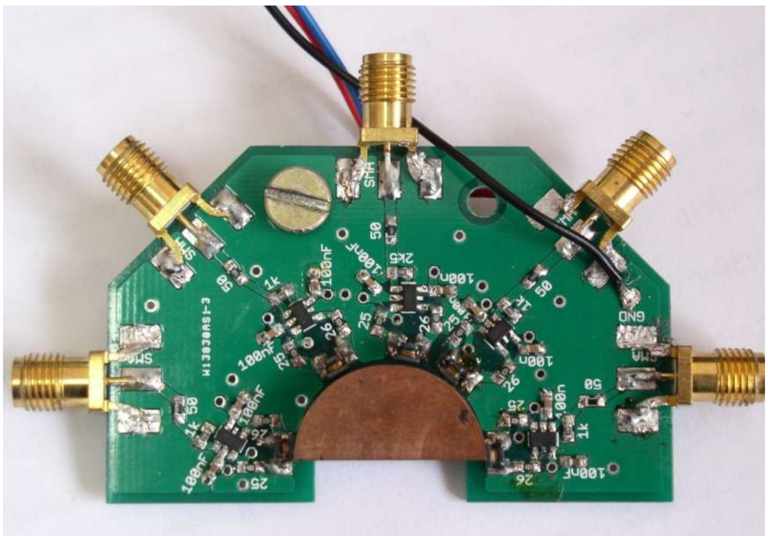

Fig.1. Image of the printed circuit board of transducers array and specimen.

The image of the printed circuit board is presented in the Fig. 1. The detection coils are commercially available inductiveness of copper wires with ferrite core. The resonance

frequency of inductiveness is 26 MHz, and inductance is about 10 uH. The linear size of the coils is constrained by the volume 2,8x2,8x2 mm^3. The coils are set to the side surface.
The pulses of LotisTii laser were focused by cylindrical lens with focus of 60 mm. The pulse energy was about 5 mJ and repetition rate was 10 Hz. The signal of PIN photodiode triggered the oscilloscope with 200 MHz bandwidth and 1 GSample/s. The averaging procedure over 64 signals was used to reduce the noise of electronics.

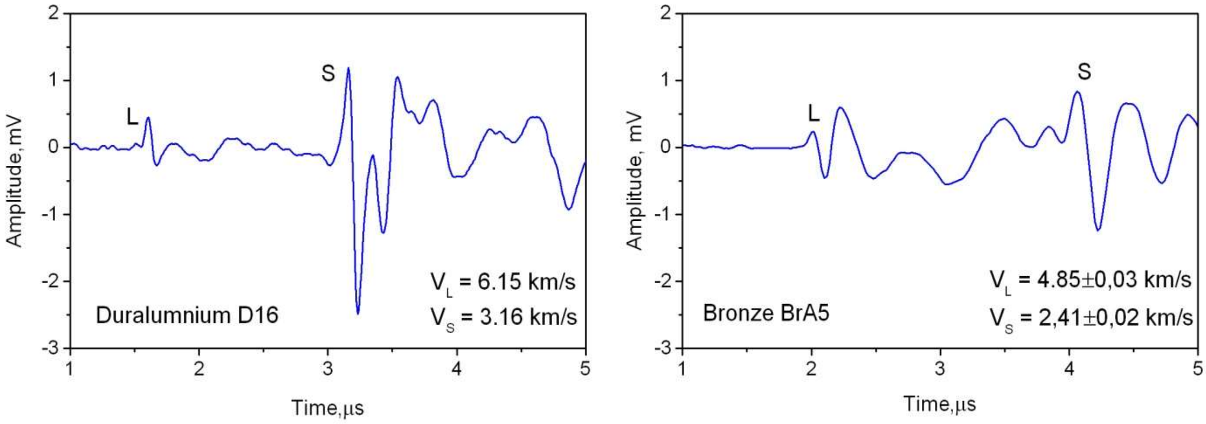

Fig.2. Signals measured in polycrystalline duraluminium and bronze. Letters ‘L’ and ‘S’ denote longitudinal and shear pulses respectively.

The examples of signals measured in polycrystalline duraluminium and bronze are presented in Fig. 2. Due to the higher value of velocity the first arriving pulse is longitudinal and the second pulse is shear. The scattering of ultrasound masks the primary pulses that shows some difficulties for distinguishing of the shear pulses. The obtained values of the velocities were used for the calculation of the elastic moduli. The density of the samples was measured by hydrostatic weighting. The resulting moduli of duraluminium and bronze are in the Table 1. The estimated error for velocity is around 2% and for the moduli not more than 4%.

Table 1. Measured elastic moduli

Material	M, GPa	G, GPa
Duraluminium D16 [Russian notation]	105	28
Bronze BrA5 [Russian notation]	196	48

4. Conclusions

The suggested scheme demonstrated possibilities of laser excitation of bulk waves and their detection by array of EMATs that shows the way of velocity measurement and elastic moduli evaluation by means of combination of laser-induced ultrasound. The considered technique is cost-effective and attractive for evaluation of metallic composites.

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