# 4.2.36. MEASUREMENT OF LOCAL POROSITY OF PARTICLES REINFORCED COMPOSITES WITH THE LASER OPTOACOUSTIC METHOD

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The problem of nondestructive testing of the actual state of composite materials is of great importance because of essential decrease of their strength caused by defects and structural changes of a material that arise during exploitation [1]. In particular, fatigue changes of composite structure lead to the increase of the volume fraction of pores (porosity) that in turn leads to the decrease of material strength even by the absence of apparent defects. So the development of local porosity measurement methods is of great practical importance to provide valuable information for residual service life evaluation of composite products.

In the present work we have proposed and realized experimentally the laser optoacoustic method for the measurements of local porosity $P$ of isotropic composite materials. It is based on measurements of phase velocities of thermooptically excited longitudinal acoustic waves in composite samples in the frequency range 0,5 – 50 MHz [2]. The local porosity (within the irradiated lateral area 1–2 mm) is determined using the dependence of phase velocity of longitudinal acoustic wave on porosity for porous metals [3] and the theoretical calculation of the phase velocity in a composite material with the two-phase medium model [4]. A number of aluminum alloy (silumin) matrix composite samples reinforced by SiC particles of a different mass concentration with the mean particle size of 14 □m was investigated.

The porosity $<P>$ averaged over the entire volume of the sample is expressed as:

$$<P> = \left(1 - \rho/\rho_0\right) \cdot 100\% \quad , \tag{1}$$

here the calculated density of the sample $\rho_0$ is determined with the known densities of the matrix – silumin ($\rho_{\mathrm{Al}}$), of the filler SiC ($\rho_{\mathrm{SiC}}$), and with the known mass concentrations $n_{\mathrm{Al}}$ and $n_{\mathrm{SiC}}$; the actual density of the sample $\rho$ is measured gravimetrically. The local porosity in different sites of a sample could be different because of nonuniform reinforcing fabrication method.

To measure the local porosity $P$ we apply the theoretical model of ultrasound propagation in a porous metal [3], where the phase velocity of longitudinal acoustic waves in a material $c_l$ depends on $P$ as follows (at the values of $P < 20\%$):

$$c_l^2 = c_{l_0}^2 \left(1 - P^{2/3}\right), \tag{2}$$

here $c_{l_0}$ is the calculated with the two-phase medium model [4] phase velocity in the investigated site of a sample:

$$c_{l_0}^2 = \frac{1}{\rho_0^2} \left[ \frac{n_{\mathrm{Al}}}{(\rho_{\mathrm{Al}} c_{l_{\mathrm{Al}}})^2} + \frac{n_{\mathrm{SiC}}}{(\rho_{\mathrm{SiC}} c_{l_{\mathrm{SiC}}})^2} \right]^{-1} . \tag{3}$$

| sample # | $n_{\mathrm{SiC}}$ | $c_{l_0}$, m/s | $c_{l_1}$, m/s | $c_{l_2}$, m/s | $P_1$, % | $P_2$, % | $< P >$, % |
|---|---|---|---|---|---|---|---|
| 1 | 0.00 | 6860 | 6670 | 6730 | 1.30±0.03 | 0.80±0.02 | 0.80 |
| 2 | 0.038 | 6920 | 6720 | 6740 | 1.43±0.03 | 1.18±0.02 | 1.45 |
| 3 | 0.077 | 6990 | 6550 | 6590 | 4.24±0.09 | 3.69±0.07 | 3.65 |
| 4 | 0.155 | 7140 | 6660 | 6680 | 4.69±0.09 | 4.41±0.09 | 4.93 |

In the expression (3) $c_{l_{\mathrm{Al}}}$, $c_{l_{\mathrm{SiC}}}$ are the known phase velocities in the matrix and in the filler [5].

The investigated samples are disks with the diameter $d$ = 40 mm. We calculate the porosity in the center (*1*) and in the periphery (*2*) sites of each sample using the expression (2) with the measured values of the phase velocities in these sites $c_{l\,1}$ and $c_{l\,2}$ and the calculated value of $c_{l_0}$ (3) for the given sample. The locality in the lateral plane is 1–2 mm and is determined by the mean diameter of the probe acoustic beam. The maximum relative inaccuracy of the phase velocity measurements is 0.5 %. The experimental results show (see the table), that the increase of the mass concentration of the filler $n_{\mathrm{SiC}}$ leads to the growth of the sample porosity $P$. All investigated samples have quite uniform distribution of pores, the local porosity values coincide within relative inaccuracy 2–3 % with the gravimetrical measurements of the average $< P >$ value. The porosity in the center of each sample is slightly higher than in the periphery.

So the proposed and realized laser optoacoustic method allows one to measure the local porosity of isotropic composite materials. This may be useful by technological development of the materials fabrication method and to reveal the sites in a material with the less strength before manufacturing of items and products.

**References:**

1. **Handbook** of Composites (ed. Herakovich C.T. and Tarnopol'skii Yu.M.). Elsevier Science Pbl., 1988.
2. **Karabutov A.A., Kobeleva L.I.** et al. // Zavodskaya Laboratoriya - Diagnostika Materialov, 2009, v. 75, № 3, p. 27 – 33 (in Russian).
3. **Polyakov V.V., Golovin V.A.** // Technical Physics Lett., 1994, v. 20, № 11, p. 54 – 57.
4. **Zharkii S.M., Karabutov A.A.** et al. // Semiconductors, 2003, v. 37, № 4, p. 468 – 472.
5. **Handbook** of Physical Quantities (ed. Grigoriev I.S., Meilikhov E.Z. and Radzig A.A.). CRC-Press, 1997.