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INVESTIGATION OF LOCAL MECHANICAL PROPERTIES OF Al-Cu-Li ALLOYS BY ACOUSTIC MICROSCOPE

The reflected scanning acoustic microscope was used for investigation of elastic properties of extruded Al-Cu-Li alloys. The local sound velocity and attenuation were measured by the V(z) curve method. The results show strong anisotropy of material due to extrusion of the sample.

1. Introduction

Modern technologies require materials working under extreme conditions with high reliability. One of the key parameters that have great impact on the life expectation of a material is its microstructure. The microstructure of green specimens can be changed. Extreme loading of material can lead to the various discontinuities, such as cracks, voids, dislocations and delaminations. Extrusion changes the shape of the grains resulting in the anisotropy of the isotropic green specimens. The development and investigation of new materials are not possible without effective method of measurement and testing their physical properties. Moreover, nondestructive testing of materials or device components is an obligatory part of every production process.

Acoustic microscopy represents very useful tool for investigation of materials. It provides a possibility for inspecting the internal structure of opaque specimens as well as quantitative evaluating the elastic properties of materials [1, 2].

We use scanning acoustic microscope (SAM) for investigation of elastic anisotropy of extruded Al-Cu-Li alloys.

2. V(z)-curve method

If the image formation requires the scanning of the object in the focal plane (2D x-y scanning), the quantitative measurement based on the $V(z)$-curve uses the scanning of the specimen towards the lens (z-direction) only. The valuable information about the specimen's elastic properties is extracted from the dependence of the output signal on the z-shift. The output signal oscillates periodically with z and the period Δz is characteristic for material [3].

There are two approaches for theoretical explanation of $V(z)$ curves: wave description, based on the Fourier optics [4] and ray approximation [5]. Due to ray approximation the spherical wave created by the lens can be expanded into a set of particular plane waves incident to the object surface at various angles from 0 to ϑ_A. The ray with direction of the wave vector represents every particular wave (Fig. 1). If the angle of incidence is equal to ϑ_R, the incident wave generates surface Rayleigh wave. The critical angle can be determined from the formula $\vartheta_R = \arcsin(v_k/v_R)$ where v_k is the velocity of bulk wave in the liquid and v_R is the Rayleigh wave velocity.

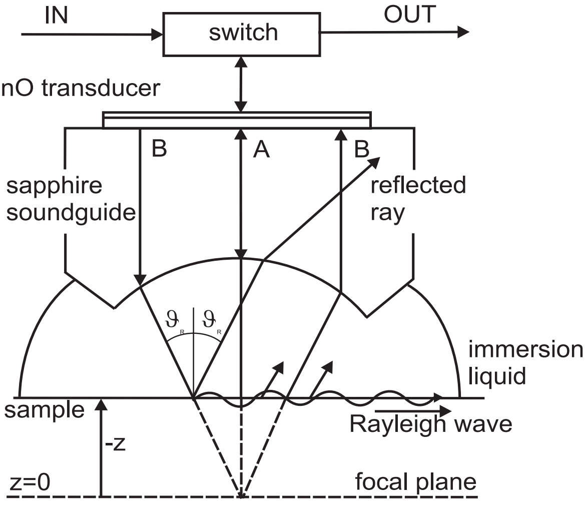

Fig. 1 The creation of output signal by two groups of waves

This surface wave is a leaky wave, it radiates the bulk wave into the immersion liquid at the angle of ϑ_R. The output signal is a result of the interference of the two groups of waves – the waves reflected from the object (ray A) and the waves radiated into immersion liquid by surface wave (ray B). These two rays give the main contribution to the output signal. The phase difference between rays A and B is

$$\Delta\varphi = \frac{2\,k\,z}{\cos\,\vartheta_R} + 2\,k_R\,z\,\mathrm{tg}\,\vartheta_R + \pi, \qquad (1)$$

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where k_R is the wave number of surface wave and k is the wave number of the bulk wave in the immersion liquid. The phase shift π is connected with phase delay of Rayleigh wave related to the bulk wave. The interference maximum occurs for the phase difference of $2\pi n$ and therefore period of oscillation of $V(z)$ curve will be

$$\Delta z = \frac{\lambda/2}{1 - \cos\vartheta_R} = \frac{v_k/2f_0}{1 - \cos\vartheta_R}\,, \qquad (2)$$

where λ is the wavelength of the bulk wave in liquid and f_0 is the ultrasound frequency. Thus, we can determine the velocity of surface acoustic wave by measuring Δz.

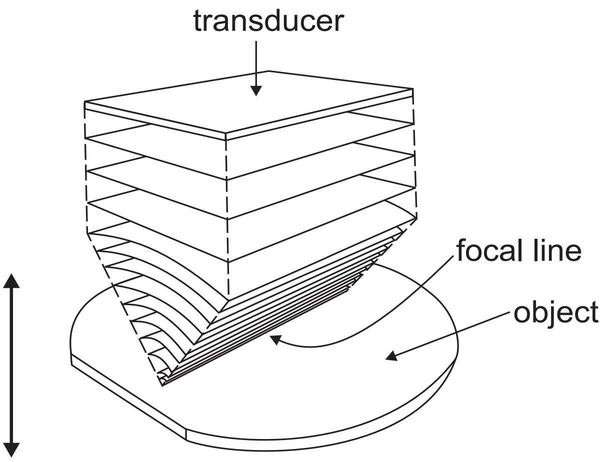


Fig. 2 Cylindrical acoustic lens

For anisotropic material where the SAW velocity depends on the direction of propagation, a cylindrical acoustic lens with line focus (Fig.2) is widely used [6 – 8]. The SAW generated by cylindrical lens has a direction perpendicular to the focal line. The periodicity of V(z) is for this case done by the same formula (2).

3. Samples

Aluminum alloys are materials of great importance in industry. Extrusions of Al-Cu-Li alloys with fiber texture often exhibit significant anisotropy and variation of mechanical properties through the profiles [9-10]. These variations depend on extrusion shape, extrusion procedure parameters and thermo-mechanical treatment parameters [11]. We investigated two alloy samples containing 2.59 Cu, 2.05 Li, 0.11 Zr, 0.04 Mg, 0.02 Si, 0.09 Fe wt. % with half of the dumb-bell profile (Fig. 3). The sample 1 was thermally treated at 530 °C and polished, the sample 2 with mat surface was not treated.

4. Experiment and results

Scanning acoustic microscope with large aperture cylindrical lens ($\vartheta_A = 2 \times 40°$) and operation frequency 250 MHz was used for obtaining the $V(z)$ curves for both samples. The measurements were carried out for the two direction: along the sample side-sill (direction A) and perpendicular to it (direction B).

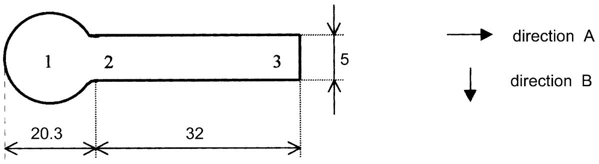


Fig.3 Positions of the measurement points in the cross-section of the AL-Cu-Li sample profile. Dimensions are given in mm.

Typical $V(z)$ curve is presented in Fig. 4, where the horizontal axis corresponds to the shift z and vertical one scales the relative values of the output signal.

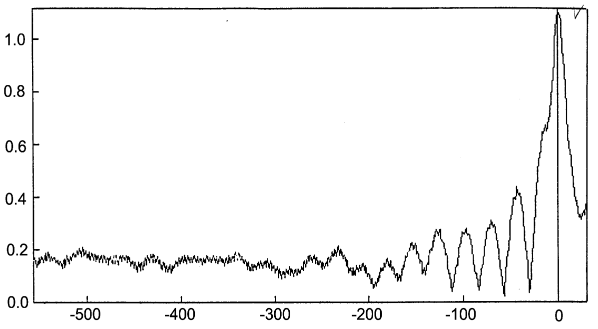


Fig. 4 V(z) - curve for sample 1, point 2, SAW direction B.

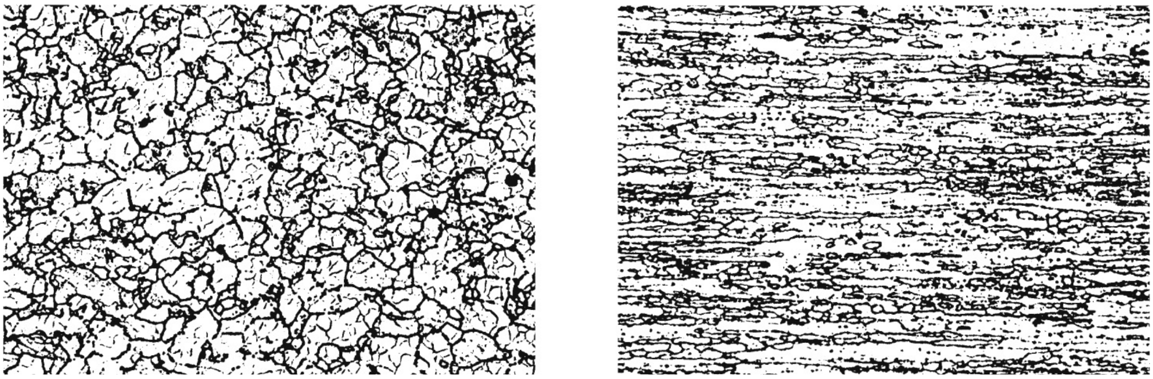
The data on SAW velocities measured in the points 1, 2, 3 are summarized in Table 1. As follows from the table, SAW velocity are higher in the sample 1 (with heat treatment and polished surface) for all points of the measurement and for both direction of SAW propagation. Taking into account that the enlargement of SAW velocity after polishing the fine ground surface is usually about 1% [12], one can deduce the reinforcing the alloy under the heating.

The presented results demonstrate also the significant variation and anisotropy of elastic properties across the cross-section of the treated sample. The SAW velocity values in point 3 are higher than the ones in point 1 for both directions of SAW propagation. At the same time the velocity of surface waves propagating perpendicular to the dumb-bell axis is lower than the velocity of SAW in the direction A (along the axis). It can be related with the changes of the material in the measured points. Fig. 5 shows the roll grain texture in the circular part of the sample 1 whereas the flattened grains befit to its rectangle part.

A large variation of SAW attenuation through the cross section was measured. The attenuation at the point 3 is noticeably higher (up to 20 dB) for SAW direction B for both samples. It can be related with the bigger scattering of the sound energy on the closest grain boundaries fallen on the length unit in direction B compared with direction A.

Table 1

Sample	Sample 1 (heating + polishing)				Sample 2			
	SAW-direction A		SAW-direction B		SAW-direction A		SAW-direction B	
Point	V M/s	α dB/mm	V m/s	α dB/mm	V m/s	α dB/mm	V m/s	α dB/mm
1	3153.7	116	3139.6	96	3074.2	97	3079.4	90
2	3127.4	69	3147.6	66	3093.7	88	3103.5	101
3	3213.7	70	3162.0	89	3094.3	87	3080.1	108



a **b**

Fig.5 The grain texture in point 1 (a) and in point 3 (b) in the cross section of extruded Al-Cu-Li sample. Magnification 200.

5. Conclusion

The obtained results demonstrate the possibility of acoustic microscopy for reliable detection of the elastic anisotropy of extruded specimens. Both acoustic velocity and attenuation were found different for two main axes of the sample cross section. On the basis of the velocity comparison for samples 1 and 2 one can conclude that the heat treatment leads to the hardening of the alloy.

References

[1] ZININ, P. V.: *Quantitative Acoustic Microscopy of Solids.* Handbook of Elastic Properties of Solids, Liquids, and Gases. Volume I: Dynamic Methods for Measuring the Elastic Properties of Solids. M. Levy, H. Bass, R. Stern and V. Keppens. New York, Academic Press. (2001), pp. 187-226.

[2] KOŠTIAL, P., BEREZINA, S., SLABEYCIUS, J.: *Utilisation of Ultrasonic Waves in the Study of Surfaces and Interfaces*, Univ. of Zilina Edition, Žilina, 1998 (in Slovak)

[3] WEGLEIN R. D., WILSON R. G.: *Characteristics Material Signatures by Acoustic Microscopy*, Electr. Lett., 14, (1978), 352

[4] ATALAR A.: *A Physical Model for Acoustic Signatures,* J. Appl. Phys., 50, (1979), 8237

[5] PARMON W., BERTONI H. L.: *Ray Interpretation of the Material Signature in the Acoustic Microscope,* Electr. Lett., 15, (1979), 684

[6] BEREZINA S. I.: *Application of acoustic microscope for determining the orientation dependences of SAW velocity in crystals.* Proc. of XI Sov. Conf. on acoustoelectronics and quantum acoustics (Dushanbe, May 1981), part 1, p.84-85 (in russian)

[7] KUSHIBIKI, J., OHKUBO, A., CHUBACHI,. N.: A*nisotropy Detection in Sapphire by Acoustic Microscopy using Line-Focus-Beam,* Electton.Lett, 17, (1981), 534

[8] BRIGGS, A., KOLOSOV, O.: *Anisotropic elastic characterization of surfaces from 2 MHz to 20 MHz. Ultrasonics,* 36, (1998), p.317-321.

[9] STARÝ, V., MACEK, K.: *Composition US. Size Distribution of Intermetallic Phases in Al Alloys(Al-Cu-Li-Zr).* Journal of Computer Assisted Microscopy. 9, No. 1, (1998) p. 45.

[10] CIESLAR, M., VOSTRÝ, P., OČENÁŠEK, V., STULIKOVÁ, I.: *Inhomogeneity of Mechanical Properties and Deformation Instabilities in Al-Cu-Li-Mg Alloy*, Material Science and Eng. A234-236 (1997), 790-793.

[11] TARDY F., NORDY, M. H., PARADIS L., BABOUX, J. C.: *Material Surface Characterization by a Rayleigh Velocity Measurement,* Proc. of Ultrasonics World Congress 1995, Berlin 1995, 451.

[12] EYRAUD, V., NADAL, M. N., GONDARD, C.: *Texture measurement of shaped Materials by Impulse Acoustic Microscopy*, Ultrasonic World Congress 99, Book of Abstracts.