INVESTIGATION OF METALLIC MATERIALS WITH ULTRASONIC METHODS

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Abstract: The paper presents two non-destructive methods for ultrasonic examination of metallic materials. The structure and strength characteristics of samples and castings of cast iron, steel and aluminum alloys were studied with the methods for measuring the information non-destructive parameters - speed and attenuation coefficient of ultrasound in the studied materials. These non-destructive information parameters provide information from the volumetric ultrasonic waves passing through the entire cross section of the material. The velocities and the attenuation coefficient of the ultrasound were calculated and a correlation of these parameters with the tensile strength in responsible castings of gray and high-strength cast irons, as well as a correlation of the hardness in tool steel samples was established. The elastic characteristics are also determined - the modulus of elasticity E (Jung's modulus) and the modulus of angular deformation (torsion) G in aluminum castings and their dependence on the structure of the controlled zones.

Keywords: ultrasonic, non-destructive information, metallic materials

1. INTRODUCTION

Ultrasonic examination of metal samples, blanks, castings and products allows assessing the structure and mechanical properties of their material without its destruction. In addition, the study of the correlations between the speed and attenuation of ultrasound, on the one hand, and the structure and mechanical properties of metallic materials, on the other hand, is a promising task.

2. OBJECTIVE

The aim of the present work is to study the structure and strength characteristics of samples and castings of cast iron, steel and aluminum alloys, by non-destructive measurement with ultrasonic methods [1]. Another task is to determine the elastic characteristics, namely the modulus of elasticity E and the modulus of angular deformation (torsion) *G* in aluminum castings and their dependence on the structure of the controlled areas.

3. RESEARCH METHODS

The work uses ultrasonic methods to study the structure and strength of materials, achieving high reliability of measurements [2,3]. A characteristic feature of these methods is the simultaneous measurement of two non-destructive information parameters, which provide information from the volumetric ultrasonic waves passing through the entire cross section of the material. These are the velocities of propagation of longitudinal and transverse ultrasonic waves and the attenuation coefficient of ultrasound in the material.

3.1 Relationship between acoustic parameters and elastic characteristics of materials.

The determination of the effective modules E and G can be done using destructive methods from the "strain-stress" diagrams at a certain scale and standard methodology. This method is very time consuming and leads to the destruction of the studied material. A simple and convenient static method for determining the elastic characteristics of a material is to measure the speed of propagation of ultrasound in the material. The modulus of elasticity E (Jung's modulus) is most often used in practice. To calculate the Young's modulus in a polycrystalline medium, the formula is used:

$$C_l = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}} \qquad (1)$$

where: Cl and Ct are the longitudinal and transverse velocities of the ultrasound in the material, respectively; Ce - speed of ultrasound in reference material. To determine the modulus of angular deformation G, the formula is used:

$$C_t = \sqrt{\frac{G}{\rho}},\ [m/s] \qquad (2)$$

where: ν - Poisson's ratio; ρ - density of the medium.

The volume velocities of propagation and the attenuation coefficient for a given frequency of ultrasound are calculated by formulas (3) and (4):

$$C = k\left(d_y / d_o\right)C_e \text{ , } [m/s] \qquad (3)$$

$$\delta_t = \frac{\left(A_1 - A_n\right) - B}{2d_o\left(n_1 - n_n\right)} \text{ , } [dB/m] \qquad (4)$$

where: k - coefficient of proportionality; n_1 and n_2 - the number of the compared pulses; d_y - relative thickness measured by ultrasound; d_o - actual thickness measured with an optoelectronic transducer; B - diffraction correction.

3.2 Research equipment

In order to determine the speed and the attenuation coefficient of ultrasound according to formulas (3) and (4), the actual and the relative thickness of the material are measured simultaneously [2,3]. The speed readings and the attenuation coefficient are shown simultaneously on the display of the digital ultrasonic device, which is a module of the automated system for complex non-destructive testing MULTITEST [3,4,5]. The device works together with a device - test pliers DK100.

Fig. 1 (a) shows the appearance of the device, together with the stepped standard, and Fig. 1 (b) shows the device DK100. The measurement methodology, the metrological provision and the instruction for operation of the device are presented in [2]. The structure and mechanical properties are evaluated by pre-prepared groups of standard samples of the tested material, the characteristics of which are used for comparison [3].

Fig.1: a) Ultrasound device MUlTITEST CD 010; b) Measuring pliers DK100.

4. ANALYSIS OF THE RESULTS OBTAINED

The basis of the ultrasound examination is the determination of the correlation between the controlled parameters of the material and the ultrasonic characteristics (speed and attenuation coefficient), which is performed with comparative samples [3,5]. In fig. 2 shows a similar correlation of cast iron castings with the same structure and pearlite base, but with the plate and spheroidal shape of graphite, classified by Rm - tensile strength. Two characteristic areas for the two types of cast iron have been formed. In fig. 2 are graphically visualized the results of automated classification of cast iron castings by strength characteristics. The crosses show the average value of three measurements of the ultrasound of cast iron castings with spheroidal graphite type "sea mines", and the circles - of cast iron castings with graphite plate type "brake drums". For the first type of castings it is important to have good strength properties (high tensile strength), while for the second type of castings it is important to have good friction and elastic characteristics. It is clear that the mechanical properties and ultrasonic non-destructive parameters of these two types of castings differ sharply from each other. The speed of ultrasound in the material, which does not meet the normal mechanical parameters for the respective type of castings, is outside the characteristic areas characteristic of these materials. It is envisaged by light or sound signal that the castings with poor mechanical characteristics will be separated from the suitable ones. In this way, a large number of castings can be measured in a short time, as the measurement process itself is automated.

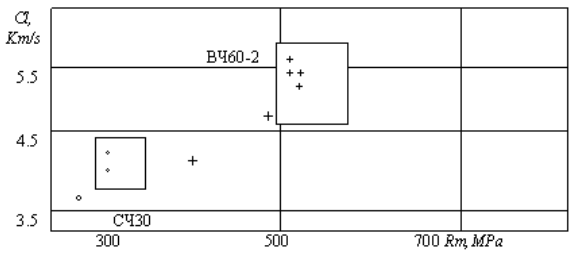


Fig.2. Classification of cast iron castings by tensile strength

The measurement of the speed and the attenuation coefficient of the ultrasound in samples of tool steel U8 depending on the hardness is shown in fig. 3. It can be seen that the speed of ultrasound decreases linearly with increasing hardness (fig. 3.a), and the attenuation coefficient increases (fig. 3.b), probably due to the increase of the internal voltage and the distortion of the crystal lattice. in the heat treatment of steel. At the attenuation coefficient, there is a relatively greater scattering of the results, probably from the different contact conditions. The dependences of the longitudinal speed of ultrasound on the hardness of aluminum.

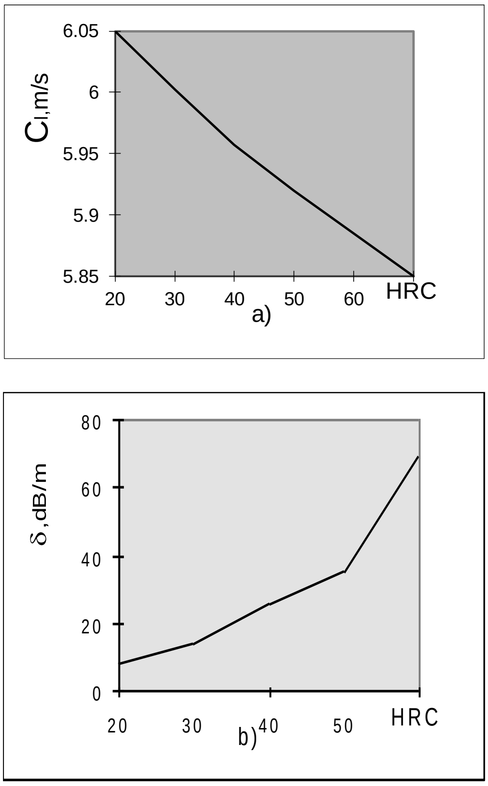
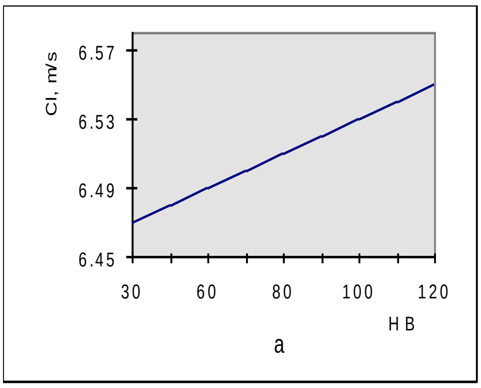


Fig.3. a) Speed and b) attenuation coefficient of ultrasound depending on the hardness of tool steels

Al9 alloy castings (car supports) are shown in fig. 4.a). Fig. 4.c) shows the dependences of the modulus of elasticity calculated by formula (1).



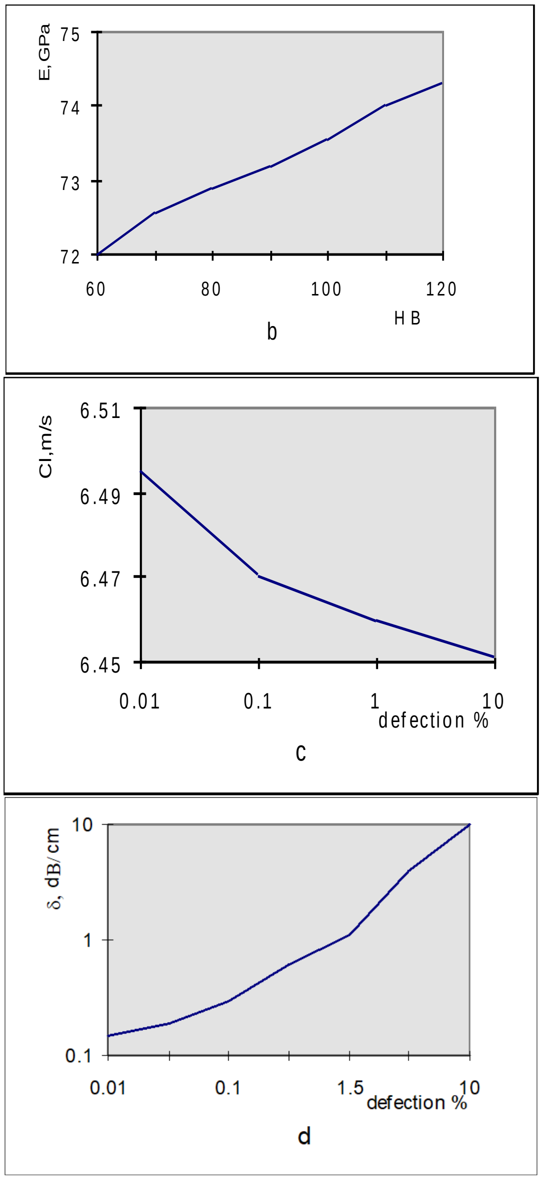


Fig.4. Dependences of the speed and attenuation of ultrasound on the physical and mechanical characteristics and the structure of castings of aluminum alloys.

It can be seen that the dependence of the Jung modulus is not entirely linear, because the densities in the measured areas of the castings are different. Figures 4.c) and 4.d) show the dependences of the ultrasound velocity on the percentage of porosity and liquation in the controlled areas. X-rays of the same areas have shown that ultrasound velocity determination is the only non-destructive method for detecting liquation that greatly reduces the mechanical properties of aluminum alloys. Liquation is a kind of defect that occurs with an improper casting regime and is expressed in the fact that silicon is released at the grain boundaries. Due to the approximately equal densities of aluminum and silicon, these defects cannot be detected by X-ray methods.

5. CONCLUSIONS

The application of the methods for automated ultrasonic measurement of velocities and the attenuation coefficient of ultrasound in the research and non-destructive testing of the strength characteristics of gray and high-strength cast iron castings, where graphite inclusions have a lamellar and spheroidal shape. In order to obtain reliable results, it is necessary to select groups of standard samples in order to create reliable characteristic areas (Fig. 2) for each specific case.

The same method can be used for non-destructive determination of the quality of heat treatment in tool steels. The capabilities of the method are also shown when measuring the speed and attenuation of ultrasound for non-destructive testing of the structure and physical and mechanical properties of responsible aluminum castings, where the requirements for quality and mechanical properties are particularly high.

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