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A method of ultrasonic study of materials

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An improved ultrasonic method for non-destructive testing of materials is proposed in the paper. The method is capable of determining material structure and mechanical properties, whereas subsequent measuring devices are designed. Moreover, the method is tested by studying the structure and physico-mechanical properties of specimens and products made of steel, cast iron and aluminum alloys. A correlation between the ultrasonic velocity and attenuation is found, on one hand, and material structure, strength and elastic characteristics are analyzed, on the other hand.

INTRODUCTION

The ultrasonic study of metal moulds, press-forms and products enables one to assess the physico-mechanical properties of the material, avoiding its destruction. Besides, the study of the correlation between the ultrasonic velocity and attenuation, on one hand, and the metal physico-mechanical properties and structure, on the other hand, turns out to be a promising task [1, 2].

1. METHOD AND AIM OF STUDY

The paper presents a method for the study of the structure and strength of materials, using ultrasonic technique. Thus, one can attain higher accuracy and reliability of the measurements. The method developed is called “Ultratest”, and its characteristic feature is the simultaneous measurement of two parameters, which provide information on volume ultrasonic waves. Those parameters are the propagation velocity of longitudinal or transverse ultrasonic waves and the coefficient of ultrasound attenuation within the material [3].

The aim of the present paper is to study and apply the “Ultratest” method in measuring the structure and strength characteristics of specimens and moulds of cast iron, steel and aluminum alloys. Another task is to find the material elastic characteristics and most of all, the moduli *E* and *G* of aluminum moulds, studying the dependence of *E* and *G* moduli on the structure of the controllable area.

2. LINK BETWEEN MATERIAL ACOUSTIC PARAMETERS AND ELASTIC CHARACTERISTICS

One can find moduli E and G by employing destructive testing methods, using "stress-strain" diagrams and applying a standard method. However, such a method is quite labor-consuming and its application results in material destruction. A simple and convenient static method of finding the material elastic characteristics is to measure the velocity of ultrasound propagation within the material. Thus, the elasticity modulus E (i.e. Young's modulus) is most often determined in practice. Ultrasonic longitudinal and transversal velocities – C_l and C_t – are measured, and X and Y quartz piezo-plates are used for that purpose. For instance, to calculate the elasticity modulus of a poli-crystal medium, one can use formulas (1).

$$C_l = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}},\ [\text{m/s}]; \qquad C_t = \sqrt{\frac{E}{2\rho(1+\nu)}},\ [\text{m/s}]. \tag{1}$$

Shear strain modulus G can be calculated by using formula (2).

$$C_t = \sqrt{\frac{G}{\rho}},\ [\text{m /s}], \tag{2}$$

where ν is the Poisson's coefficient and ρ is the medium density. One can also calculate the volume velocity of propagation and the damping coefficient under a specific ultrasonic frequency t by means of formulas (3) and (4).

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

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

where C_e in formula (3) is the previously known velocity of ultrasound propagation in a standard material; k is proportionality coefficient; d_y is the relative thickness of the mould controllable area measured by using ultrasonic technique; d_o is the real thickness of the controllable area measured by using an optical-electronic transducer. The notations used in formula (4) are as follows: n_1, n_n are the numbers of the compared impulses and B is the previously known diffraction correction.

3. INSTRUMENTS AND METHODS OF STUDY

To find the ultrasonic velocity and attenuation, using formulas (3) and (4), we apply the "Ultratest" method and subsequent methods of measuring the ultrasonic velocity and attenuation in solid materials. Note that we simultaneously measure the real thickness of the studied material and the path covered by the ultrasonic wave [1] in the material. Material structure and mechanical properties are assessed by testing previously fabricated standard specimens whose characteristics are used for comparison. Note that a basis of the ultrasonic control should be the correlation (if any) between the material controlled characteristics and the ultrasonic parameters (attenuation coefficient and velocity).

To realize the method, we design a device that can jointly operate with an ultrasonic defectoscope or thickness-measurer. Testing pliers type DK100 are also of practical interest, and technical drawings for their assembly are shown in Fig. 1. Note that one can use pliers either in laboratory or in industrial production. The controllable specimen or the controllable area of the product are pressed by means of the trigger 17, applying constant pressure between the tempered center 25 and the ultrasonic piezo-transducer. The latter measures the real thickness of the material controllable area. The optical-electronic transducer that measures the real thickness of the material controllable area is mounted in casing 4. The signals obtained are electronically processed by using microprocessor, while velocity and coefficient of attenuation are calculated by means of formulas (3) and (4). The ultrasonic defectoscope (thickness-measurer), the introduced microprocessor and pliers DK100 operate in a unified system, being attuned by means of a step-wise standard specimen fabricated of ARMCO iron. Measurement data are processed by the microprocessor, which executes a specially designed program. Thus, C [m/s] and δ [dB/m,] i.e. the average values of the ultrasound two parameters, as well as the parameter upper and lower limits, are found.

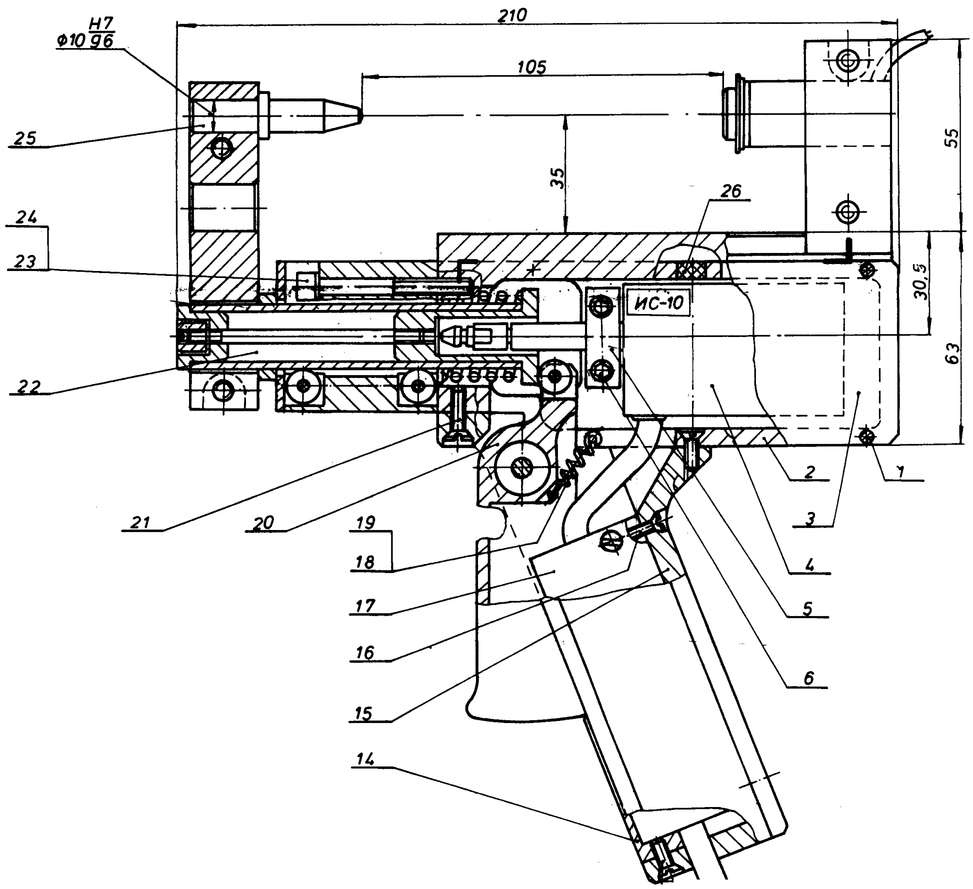

Fig. 1. Technical drawing of the assembly of DK100 pliers

4. EXPERIMENTAL STUDY

The experimental study employs standard methods of analysis, i.e. metalographic and chemical methods, mechanical testing, density determination etc. X-ray and ultrasonic defectoscopy are also used to localize internal macro-defects in the specimen and in the mould measurement areas. We perform classification of steel and cast iron specimens, as well as that of moulds of modified cast iron. However, mould classification is performed by using the testing pliers DK100 in the most crucial areas and by considering the mean value of three independent measurements. Fig. 2 presents the classification of moulds of modified cast iron, regarding material structure and strength characteristics. The confidence intervals of the velocity of the ultrasonic longitudinal wave form characteristic areas on the standard specimens, whose structure and strength characteristics are previously known. Those areas involve two types of cast iron: Spheroid-graphite cast iron (SGCI) 60 and Gray cast iron (GCI) 30. After determining the characteristic areas, we perform practical classification of the moulds, following the technical requirements. For instance, the mould type “brake drum” used in heavy-freight trucks possess the best technological properties if they are prepared of gray cast iron, type (GCI) 30, whose structure is homogeneous. Requirements to moulds, type “mine case”, are different from those given so far, whereas the most appropriate material is high-strength spherical-graphite cast iron, type (VCH) 60. Fig. 3 shows the velocity and the attenuation coefficient of a longitudinal ultrasonic wave, depending on the hardness of products (press-forms) of instrumental steel. Fig. 4 shows dependence of the acoustic parameters (velocity and attenuation of the ultrasonic waves) of aluminum alloys on the hardness and damage percentage. The elastic characteristics and most of all moduli E and G of moulds of aluminum alloys, are calculated. Moulds are prepared by using the method of counter-pressure moulding. The alloys used are Anticorodal 70 and Al-9, and moulds are type “carrier” used in vehicle driving section. Mould dependence on the structure of its controllable area is also studied. The alloy relative weight is included in formulas (1), (2), (3) and (4). Density in the porous areas of the aluminum mould is found, It is related to mould fracture. Hence, the mean relative weight of a metal piece without pores, and that of a mould cast by means of counter-pressure moulding, are considered. The calculated moduli are a bit larger than the real ones, valid for the porous area, but this does not interfere with the present study.

5. ANALYSIS OF THE RESULTS FOUND

Fig. 2 shows graphically the results of the classification of cast iron moulds, regarding their type and strength characteristics. The crosses show moulds type “mines” while the circles – moulds type “brake drums”. It is clearly seen that the two types differ from each other. Determination of hardness and tension strength of moulds which do not belong to those types (i.e. moulds that are out of the characteristic areas) shows that their mechanical characteristics lie outside the limits of the cast iron types considered.

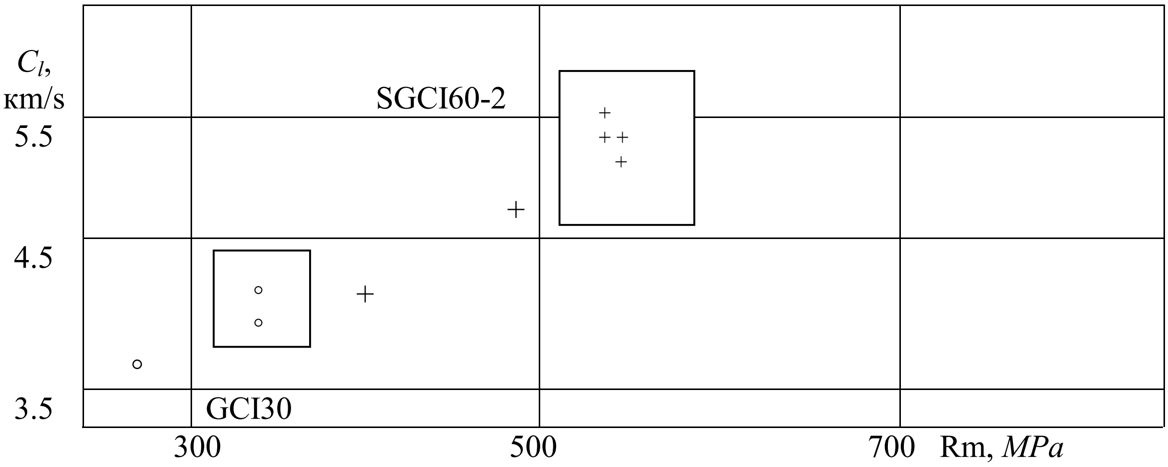

Fig. 2. Classification of cast iron moulds with respect to material strength characteristics

The measurement of the ultrasonic velocity and attenuation in instrumental steel (Fig. 3a and Fig. 3b) show that the ultrasonic velocity decreases proportionally to the hardness increase. This is probably due to the increase of the internal stresses and to the distortion of the crystal lattice that take place under thermal treatment (Fig. 3a). Opposite to those phenomena, hardness increase yields increase of the attenuation coefficient, but the results show more significant scatter due to the non-similar conditions of measurement contact. Hence, the ultrasonic velocity is the most appropriate parameter, which would integrally assess the quality of the thermal treatment of instrumental steel products (press-forms).

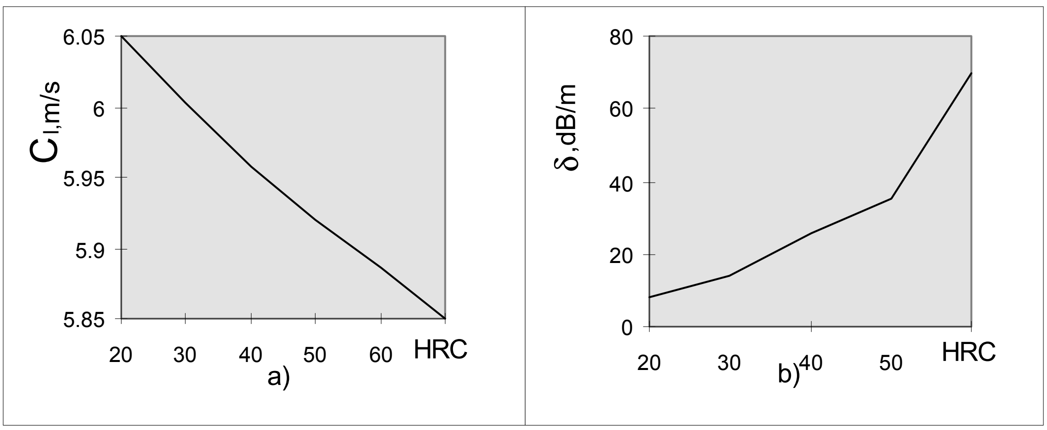

Fig. 3. Ultrasonic velocity and attenuation coefficient as depending on the hardness of instrumental steel

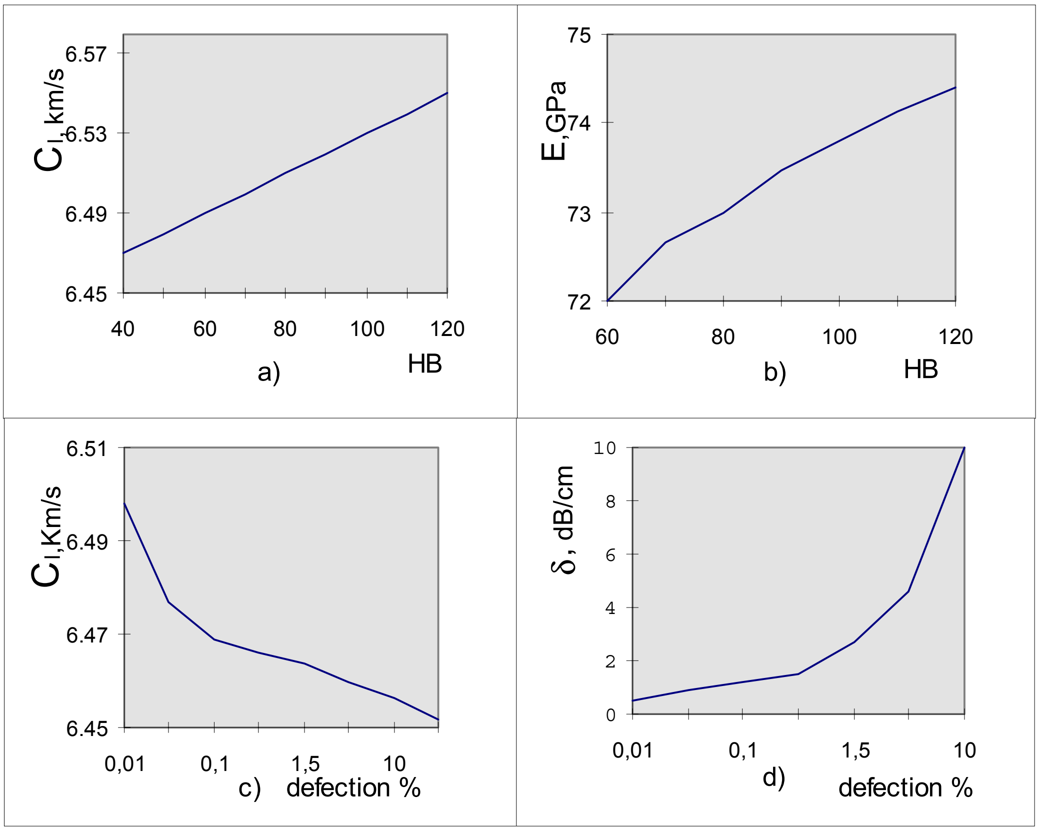

Fig. 4. Dependencies of the ultrasonic velocity and attenuation on the physico-mechanical characteristics of aluminum alloys

The dependence of the ultrasonic longitudinal velocity on the hardness of aluminum moulds is shown in Fig. 4a, while that of the elasticity modulus *E* – in Fig. 4b. Measuring the ultrasonic longitudinal velocity in moulds of aluminum alloys, one can note its well expressed linear dependence on hardness (Fig. 4a). Fig. 4b shows similar dependence of the elasticity modulus on hardness. To determine the damage percentage, we prepare ultrasonic and X-ray damage-grams in the controllable area of each mould. Using the damage-grams, one can localize two types of defects: segregation and porosity. Both types of defects significantly deteriorate the alloy mechanical properties. One can not localize easily segregation in the X-ray photographs, but it is registered by means of ultrasonic defectoscopy. Porosity is clearly seen in the X-ray photographs, while it, together with segregation, are hardly localized on the ultrasonic damage-grams. However, the segregation is a specific defect that occurs during incorrect moulding regime. It is expressed in that silicon segregates at the boundaries of grains whose sized is 1–5 mm and larger. Due to the approximately one and the same density of Al and Si, those defects can not be localized by means of the X-ray defectoscopy. Using a special algorithm and joining the two defects, we calculate the percentage of damage in each controllable area. Fig. 4c and Fig. 4d show dependencies of the ultrasonic longitudinal velocity and attenuation coefficient on damage and under frequency of 5 MHz. These parameters are measured in the mould controllable areas. It is seen that the velocity of ultrasound propagation is strongly affected by both types of defects. It sharply decreases with the increase of the percentage of relative damage (Fig. 4c). Attenuation does not vary significantly under segregation, but it increases under porosity (relative damage 1–10%). Hence, one can use this acoustic characteristic for the non-destructive determination of the defect type (Fig. 4d).

6. CONCLUSIONS

A method of automated measurement of ultrasonic velocity and attenuation in solid materials is designed. The applicability of the method is proved. Control of the strength characteristics of cast iron moulds, where graphite inclusions have plate and spheroid shape, is performed. However, to obtain reliable results, one needs to precisely select the standard specimens, in order to outline reliable characteristic areas in each specific case.

The method can be used for the estimation of the quality of instrumental steel that has undergone subsequent thermal treatment. The capability and advantages of the method are illustrated by measuring the ultrasonic velocity and attenuation coefficient during non-destructive control of the structure and mechanical properties of aluminum moulds. Some of the alloy elastic characteristics, i.e. elasticity modulus E, shear modulus G and Poisson coefficient are calculated. The results found can be used in non-destructive testing of aluminum moulds, when requirements to mould mechanical characteristics are high.

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