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MEASUREMENT OF ELASTICITY MODULUS USING ULTRASONIC AND VIBRATION METHOD

MĚŘENÍ MODULŮ ELASTICITY POMOCÍ ULTRAZVUKOVÝCH A VIBRAČNÍCH METOD

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Abstract

In this paper determination of elasticity modulus using nondestructive ultrasonic and vibration methods is presented. Ultrasonic method was done by high precision ultrasonic thickness gauge. In a tested piece of known dimensions sound velocity is measured. From measured velocity statical and dynamical elasticity modulus was calculated. In vibration method, natural frequency of transverse vibration of tested piece was measured using high sensitivity accelerometer. Tested specimen was treated as Bernoulli cantilever beam. Modulus of elasticity was determined by putting values of natural frequency, moment of inertia and length of tested piece in expression for natural frequency for this kind of beam. From results analysis for these two methods arises the possibility of their using for quick, cheap and nondestructive determination of elasticity modulus.

Key words: modulus of elasticity, measurement, ultrasonic, vibration

1. Introduction

Modulus of elasticity is one of the primary and certainly the most important characteristics of materials from the viewpoint of mechanical characteristics. All calculations of mechanical constructions perform in the elastic field of material, therefore, modulus of elasticity of material is a constant that is relevant for these calculations. It is usual that modulus of elasticity of solid bodies is determined by testing materials on the backlash, which is performed on tensile test machine. For these tests is necessary to prepare specimen accurately defined by the rules. Besides that, this process of preparing specimen is rather demanding process and this testing is high expensive. In addition, modulus of elasticity is a constant of the material on which depend some other properties of materials such as the spreading speed of sound in the material, natural frequencies, etc. If the dependence between these features and modulus of elasticity is known, it is possible to indirectly measure modulus of elasticity of the material by measuring these features. In this paper is made a comparison of two indirect methods of measurement modules of elasticity, the first one is ultrasound measuring modulus of elasticity, and the other one is based on the beam natural frequency measurement.

2. Specimen properties

Experiment is done on specimens that are made of high-alloyed Cr – Ni steel. Five specimens were made from plate of nominal thickness value 16 mm. Specimen dimensions were measured using sliding caliper of accuracy 0.05 mm, while the mass is measured with precision scale of accuracy 0.01 g. Density of each specimen was calculated using measured values of dimensions and mass. These specimen characteristics are given in the Table 1.

Table 1 Specimens properties for ultrasonic measurement

Specimen	Length l [mm]	Width b [mm]	Thickness h [mm]	Mass m [g]	Mass density ρ [g/cm^3]
No.1	254.99	22.12	15.92	693.6	7727.0575
No.2	255.03	22.17	15.83	691.7	7727.7624
No.3	254.91	22.13	15.83	689.9	7722.8943
No.4	254.92	22.23	15.85	694.9	7735.4317
No.5	254.89	22.22	15.77	690.5	7733.7851

Table 2 Specimens properties for natural frequency measurement

Specimen	Length l [mm]	Width b [mm]	Thickness h [mm]	Mass m [g]	Mass density ρ [g/cm^3]
No.1	238.0	15.8	4.1	131.2	7727.0575
No.2	238.5	15.8	4.063	123.9	7727.7624
No.3	238.0	15.8	4.063	126.1	7722.8943
No.4	238.0	15.8	3.975	124.3	7735.4317
No.5	238.1	15.8	3.966	123.9	7733.7851

After ultrasonic measurements completion each specimen was fine machine treated and brought to the form suitable for the method based on the measurement of natural frequencies. Dimensions of tested pieces were made so that the ratio of thickness and height is approximately 4, in order to avoid two-plane specimen vibration. Specimens are treated as Euler slender beams, and their dimensions are given in Table 2. Unlike the previous case material density is already known.

3. Ultrasonic measurement of modulus of elasticity

Sound is mechanical wave, which means, its spreads through a medium by oscillation of particles of medium through wave extend. Main parameters of sound waves are amplitude and frequency. In frequency dependence sound waves are divided into:

- Infrasound under 16 Hz,
- 16 Hz – 20 kHz sound hearable for human ear and
- Ultrasound above 20 kHz

In dependence of movement of some medium particles there are longitudinal and transverse sound waves. In longitudinal waves, the oscillations occur in the longitudinal direction or the direction of wave propagation. In the transverse or shear wave, the particles oscillate at a right angle or transverse to the direction of propagation. The longitudinal waves can be generated in gases and liquids as well in solids, while transverse waves can be generated only in solids. Velocity of longitudinal waves in some medium can be determined from the expression [1]:

$$c_l = \sqrt{\frac{E}{3\rho(1-2\nu)}}, \qquad (1)$$

where are: c_l – longitudinal wave velocity [m/s], ρ – mass density of medium [kg/m^3], ν – Poisson ratio, E – modulus of elasticity [Pa].

So, if it is known density of medium, Poisson ratio and velocity of longitudinal sound waves, it can be calculated medium modulus of elasticity. In experiment presented in this paper velocity of longitudinal waves in specimens which dimensions and density are shown in Table 1 was measured. Sound velocity was measured by ultrasonic thickness gauge GE DM4, while ultrasonic probe of 5 MHz longitudinal waves frequency was used (Figure 1).

Fig. 1 GE DM4 ultrasonic thickness gauge

This device measures thickness by pulse echo overlap method, which means it measures time between transmitted and received the same echo reflected from backwall. From known velocity of sound and the time it calculates thickness of measured specimen. This device uses ultrasonic probe with two piezo transducer, where one of them is transmitter and another is receiver. This device accuracy is 0.01 mm in range 0 ÷ 99.99 mm, and 0.1 mm in range 100 ÷ 500 mm. Calibration is needed for any material which is measured. Calibration can be done on two different ways; first one is to insert sound velocity and second is calibration on calibration block of same material.

In the experimental part of this paper thickness gauge is calibrated on tested specimens onto mechanical measured thickness. That way the velocity of sound is determined in measured point of specimen expressed in m/s. From this data using expression (1) is calculated modulus of elasticity. For the calculation is used Poisson ratio $\nu = 0{,}3$, value from table, which is disadvantage of measurement. Modulus of elasticity is measured in rolling direction and perpendicular onto rolling direction. Calculated values are shown in table 3.

Table 3 Calculated dynamical modulus of elasticity

Specimen	No. 1	No. 2	No. 3	No. 4	No. 5
E_{dyn} [GPa]	192.299	191.896	194.418	1,95.602	195.56

Because of the relatively small movement of particles in the material through which the is transmitting sound wave, the expression (1) gets dynamic modulus of elasticity that is different from the modulus of elasticity measured by tensile test machines. The connection between static and dynamic module of elasticity is given the following expression:

$$E = 1{,}25 E_{dyn} - 19\,, \qquad (2)$$

where are: E – static modulus of elasticity and E_{dyn} – dynamic modulus of elasticity.

4. Vibration measurement modulus of elasticity

Natural frequency is a characteristic feature of all types of materials. Depends on several factors, among others, and the modulus of elasticity. In this fact is reflected the possibility of indirect measurement modulus of elasticity by direct measurements of specimen's free vibration. Vibration measurement is done by using SPIDER 8 amplifier, and KS91 miniature accelerometer as a signal transducer. These devices come with control software Catman Professional, which is used for postprocessing of measured vibrations. On this way, we obtained natural frequencies of tested specimens. The experimental setup is shown in the Figure 2, consisted from the computer, specimen, clamping device, base, amplifier and accelerometer.

Fig. 2 Experimental setup for vibration method

In Fig. 2 is also shown a separate detail of the accelerometer on a measuring position, which is located on the clamping device. Accelerometer of high sensitivity is not placed directly on the test piece in order to avoid the impact of its mass on the results of measurements. Clamping device is configured to accept part of specimen, what reflects in specimen free length. This fact directly determines a free part of specimen. Values of natural frequencies, which are obtained by vibrations record postprocessing, are shown in Table 4.

Table 4 Lowest natural frequencies of specimens

Specimen	f [Hz]
No. 1	56.32
No. 2	55.66
No. 3	53.91
No. 4	52.73
No. 5	54.20

Dependence of the lowest natural frequency on the modulus of elasticity is given by equation:

$$f = \frac{0.562}{l^2} \cdot \sqrt{\frac{EI}{\rho A}}, \tag{3}$$

where are: E – modulus of elasticity, f – natural frequency, l – specimen free end length, ρ – material mass density, A – area of cross-section, I – moment of inertia.

Transforming this equation and the substitution of known and measured quantities, it is reached the value modulus of elasticity of samples on which the measurement is performed. Calculated values of the dynamic modulus of elasticity for each of the test piece are shown in Table 5.

Table 5 Calculated values of dynamic elasticity modulus

Specimen	No. 1	No. 2	EP No. 3	No. 4	No. 5
E_{dyn} [GPa]	177.74	178.28	165.74	165.9	176.3

5. Result discussion

The comparison of the results obtained by using both of methods is presented in the Fig. 3 through their normal distributions.

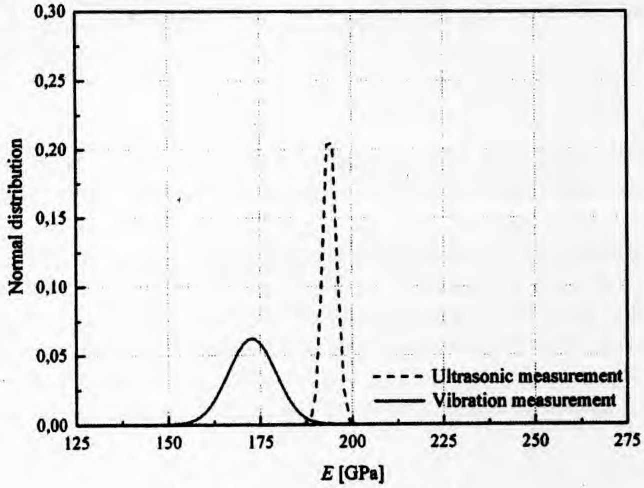

Fig. 3 Comparison of results

The difference of mean value predicted by two methods is about 10%, where greater value is given by ultrasonic method. Ultrasonic method has 3.5 times less dissipation of results then results obtained by usingvibration method.

The results of ultrasonic method highly depend on assumed value of Poisson ratio of tested material. Vibration method doesn't require Poisson ratio, but highly depends on precision of specimen thickness measurement. Vibration method needs highly precise of specimen machining, while ultrasonic method could use any specimen with two parallel sides and thickness greater than 12 mm.

6. Conclusion

In this paper comparison of ultrasonic and vibration method for measurement of modulus of elasticity is presented. Obtained values of modulus of elasticity differ only in about 10%, while dispersion of results is significantly greater in case of vibration method. Application of ultrasonic method is simpler then vibration method in sense of specimen preparation and dependence of results on precision of specimen machining. Vibration method doesn't require Poisson ratio, while it ultrasonic method does, what is its main disadvantage. Introducing measurement of velocity of transverse sound waves this disadvantage could be removed.

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