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DETERMINATION OF ELASTIC AND PLASTIC CHARACTERISTICS OF TiC–TiNi ALLOYS BY THE ULTRASONIC RESONANCE METHOD

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Elastic characteristics and propagation velocities of ultrasonic waves in a TiC–TiNi *composite material are determined by the ultrasonic resonance method. The values of the elastic moduli of the solid composite obtained are used to estimate its plastic properties. The effect of various additives on the elastic and plastic properties of the composite is studied.*

An analysis of the specific features of stress-wave propagation in elastic bodies shows that the velocity of wave motion is constant for a given medium and depends on its elastic properties [1, 2]. Properties of solid composite materials of complex inhomogeneous structure strongly depend on the character of an external action and temperature. Therefore, characteristics of wave motion are determined not only by elastic properties but also by plastic properties and structural inhomogeneities of hard alloys.

At present time, ultrasonic vibrations are used to study elastic and inelastic characteristics of hard alloys. In particular, the ultrasonic resonance method of analyzing the strength and inhomogeneity of a material is based on measuring the velocity of an ultrasonic pulse whose magnitude depends on elastic properties and density of the hard alloy.

In the present work, we use the resonance method of continuous vibrations proposed in [3, 4]. Figure 1 shows schematically a composite vibrator. A specimen with glued quartz transducers is fixed by means of a special holder. An ultrasonic signal from a generator, which is varied continuously within the frequency range 1–10 MHz, passes through the specimen and arrives at the amplifier. The frequency of the signal is measured by the frequency meter when resonance occurs, i.e., when the voltage at the vacuum-tube voltmeter reaches a maximum. The diameter of sintered specimens matches the size of a cell enclosing the specimen. The specimens were sintered in a vacuum furnace. The method of producing the composite material and its structural characteristics are described in [5].

The propagation velocities of the longitudinal (v_l) and transverse ($v_{\rm trans}$) ultrasonic waves of continuous vibrations whose frequency was varied within the frequency range 1–10 MHz were determined experimentally at room temperature. The values of v_l and $v_{\rm trans}$ were calculated by the formulas

$$v_{\rm long} = 2l\Delta f_x[1 + \rho_{\rm t}l_{\rm t}/(\rho_{\rm s}l_{\rm s})], \qquad v_{\rm trans} = 2l\Delta f_y[1 + \rho_{\rm t}l_{\rm t}/(\rho_{\rm s}l_{\rm s})],$$

where $\rho_{\rm t}$ and $\rho_{\rm s}$ are the densities of the quartz transducer and specimen, respectively, $l_{\rm t}$ and $l_{\rm s}$ are the lengths of the quartz transducer and specimen, respectively, and Δf_x and Δf_y are the average differences between the frequencies of neighboring harmonics. The elastic moduli were determined by the relations [1, 2]

$$E = 2G(1+\mu), \quad G = \rho\vartheta_t^2, \quad K = \frac{E}{3(1-2\mu)}, \quad \mu = \frac{1 - 0.5(v_{\rm long}/v_{\rm trans})^2}{1 - (v_{\rm long}/v_{\rm trans})^2}. \tag{1}$$

Here E is Young's modulus, G is the shear modulus, K is the compressibility factor, μ is Poisson's ratio, and ϑ_t is the longitudinal velocity of sound.

The resonance frequencies depend on the specimen thickness and velocity of sound in them (the effect of the transducers is taken into account by a small correction factor). The spectrum of the composite vibrator contains several spectral lines separated by nearly equal frequency intervals.

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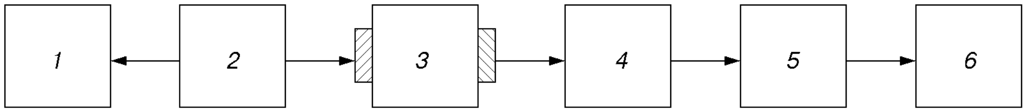

Fig. 1. Diagram of a composite vibrator: 1) frequency meter; 2) high-frequency generator; 3) specimen; 4) broadband preamplifier; 5) broadband amplifier; 6) vacuum-tube voltmeter.

TABLE 1

Volume composition of the alloy	pv_{long}, m/sec	v_{trans}, m/sec	P,%
30% TiC–70% TiNi	7089.3	3619.5	2
40% TiC–60% TiNi	7314.4	3849.5	3
50% TiC–50% TiNi	7934.1	4686.5	1
50% TiC–40% TiNi–10% Ti	7990.0	4645.0	1
60% TiC–40% TiNi	7641.9	4358.4	8
70% TiC–30% TiNi	7716.4	4258.2	10
50% TiC–49.5% TiNi–0.5% B	7482.1	4207.8	2
50% TiC–49% TiNi–1% B	7556.6	4221.9	2.8
50% TiC–48.5% TiNi–1.5% B	7616.4	4306.1	2.2
50% TiC–48% TiNi–2% B	7811.6	4511.0	1.5
50% TiC–49.5% TiNi–0.5% Ni	7994.13	4686.52	3
60% TiC–39.5% TiNi–0.5% Ni	7641.86	4358.41	4
50% TiC–10% TiN–40% TiNi	7180.3	4192.7	4.5
40% TiC–20% TiN–40% TiNi	7244.87	4034.61	5
30% TiC–10% TiN–60% TiNi	7350.0	3830.0	7

Specimens made of a TiC–TiNi composite hard alloy with parallel surfaces (deviation did not exceed 10^{-3} rad) were tested on the ultrasound installation. Surface finish of the specimens corresponded to the 7th class of roughness or higher. The error in determining the elastic moduli did not exceed 2%. Given the experimental values of the elastic moduli, we calculated the elastic moduli of a pore-free specimen using the equation [6]

$$\frac{E}{E_0} = \frac{G}{G_0} = \frac{K}{K_0} = 1 - 15P\,\frac{1-\mu}{7-5\mu},$$

where P is the porosity; the subscript 0 refers to the pore-free specimen. It was assumed that Poisson's ratio is independent of the specimen porosity. The measured velocities of longitudinal and transverse ultrasonic waves are listed in Table 1.

The experimental results show that the velocities of longitudinal and transverse waves initially increase and then decrease as the volume fraction of the carbide component of the alloy increases. The decrease in v_{long} and v_{trans} is probably due to the higher porosity of the specimens; in these specimens, ultrasonic signals attenuate rapidly. One can see from Table 1 that introduction of small boron additives (from 0.5 to 2%) into a 50% TiC–50% TiNi alloy also increases the velocities of longitudinal and transverse ultrasonic waves. Specimens made of 50% TiC–50% TiNi, 50% TiC–48% TiNi–2% B, and 50% TiC–40% TiNi–10% Ti compositions are less porous; therefore, the propagation velocities of ultrasonic waves in these specimens are higher under normal conditions ($T = 293$ K).

Dependences of Young's modulus, shear modulus, Poisson's ratio, and compressibility factor on the specimen composition were determined under normal conditions by formulas (1).

Figures 2 and 3 show the experimental results. One can see that E and G decrease monotonically and Poisson's ratio increases almost linearly as the volume fraction of the binding phase TiNi increases from 30 to 70% (see Fig. 2). Since the elastic moduli of metal carbides and diborides are high, the values of E and G increase with the volume fraction of the carbide phase and boron additive in the alloy (see Figs. 2 and 3). The compressibility factor depends on the volume fraction of the binding phase only slightly. For hard alloys, the experimental dependence of Young's modulus on the volume ratio of the components is described well by the formula

$$E = (E_{\text{TiC}} V_{\text{TiC}} + E_{\text{TiNi}} V_{\text{TiNi}})/V,$$

where E_{TiC} and E_{TiNi} are Young's moduli of titanium carbide and titanium nickelide, respectively.

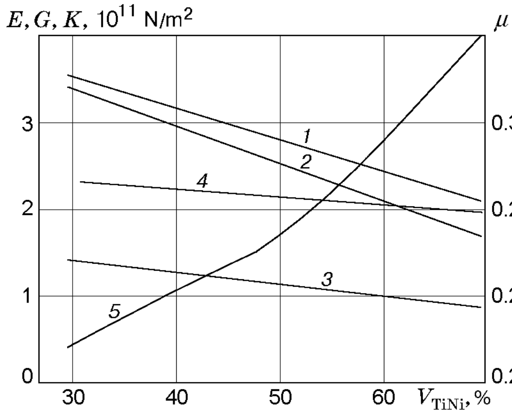

Fig. 2

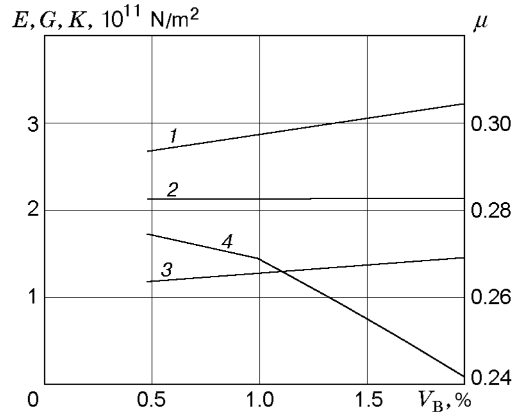

Fig. 3

Fig. 2. Elastic moduli and Poisson's ratio versus the volume fraction of the binder in a TiC–TiNi alloy: curve 1 refers to E (experiment), curve 2 to E (theory), curve 3 to G, curve 4 to K, and curve 5 to μ.

Fig. 3. Elastic moduli and Poisson's ratio versus the volume fraction of boron in a TiC–TiNi alloy: curves 1–4 refer to E, G, K, and μ, respectively.

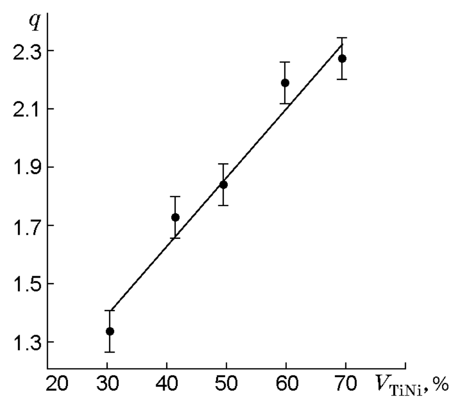

Fig. 4

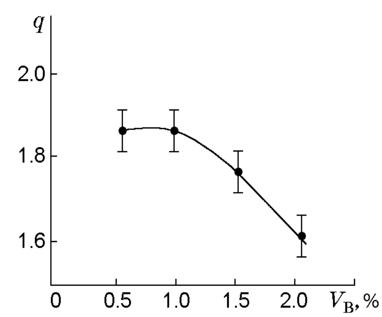

Fig. 5

Fig. 4. Plasticity of the hard alloy TiC–TiNi versus the volume fraction of the binder: the points are the experimental data and the curve is their approximation.

Fig. 5. Plasticity of the hard alloy 50% TiC–$(50 - x)$% TiNi–x% B versus the volume fraction of boron: the points are the experimental data and the curve is their approximation.

Addition of boron in amounts of more than 2% to the alloy composition results in the formation of the brittle phase TiB_2, disappearance of the plastic phase TiNi, and higher porosity; therefore, the elastic characteristics of these specimens were not measured.

Given the elastic moduli of a composite material, one can estimate the plastic properties of the material. As a plasticity characteristic, we used the ratio of the compression modulus to the shear modulus $q = K/G$ [7].

The plasticity of hard alloys increases linearly as the volume fraction of the binding phase increases from 30 to 70% (Fig. 4). The reason is that the highly plastic phase TiNi remains in the alloy after sintering. The hard alloys 50% TiC–50% TiNi, 50% TiC–40% TiNi–10% Ti, and 50% TiC–49% TiNi–1% B possess the highest strength and mechanical characteristics.

Introduction of boron in small amounts (0.5–1.0%) into the alloy slightly increases the plasticity of the material by purifying and deoxidizing the surfaces of interacting components, which intensifies their interaction in sintering. As the volume fraction of boron increases to 1% or more, a new phase — titanium diboride (TiB_2) — is formed. This phase is highly brittle, and, hence, the plasticity of the material becomes less pronounced (Fig. 5).

TABLE 2

Volume composition of the alloy	K, 10^{10} N/m^2	G, 10^{10} N/m^2	q
50% TiC–10% TiN–40% TiNi	21.51	11.61	1.72
40% TiC–20% TiN–40% TiNi	20.41	10.80	1.89
30% TiC–10% TiN–60% TiNi	21.31	11.61	1.84
50% TiC–49.5% TiN–0.5% TiNi	23.99	13.60	1.76
60% TiC–39.5% TiNi–0.5% N	24.77	15.71	1.57
50% TiC–40% TiNi–10% Ti	24.90	13.05	1.91

The calculated elastic and plastic moduli are listed in Table 2. One can see that introduction of titanium nitride (TiN) in amounts of 10–20% into the alloy slightly increases the plasticity of the material. Titanium nitride is known to be more plastic than titanium carbide. Small nickel additives make the alloy less plastic. The reason is that the brittle phases $TiNi_3$ and $TiNi_2$ are formed upon interaction between nickel and titanium in sintering. Because of these phases, the material becomes less plastic and more brittle.

Introduction of free titanium into the alloy TiC–TiNi prevents the formation of brittle phases $TiNi_3$ and $TiNi_2$ and preserves the plastic phase TiNi. The value of q in this alloy increases to 1.91.

Thus, it may be concluded that the low-melting-point component of titanium nickelide has a pronounced effect on elastic and plastic properties of composite materials. Introduction of certain additives into the composite material intensifies the interaction of phases in sintering and improves physicomechanical properties of the material.

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