Elastic Characteristics of Fibrous Metals

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In the present work, the elastic characteristics of fibrous metals (dynamic modulus of elasticity and damping decrement) were determined with specimens fabricated from fibers of copper and Kh18N9T stainless steel. The fibers were produced by calibrated machine cutting of an initial wire 50 µm in diameter into segments 7 mm long, i.e., with a length to diameter ratio of 140. The initial fibers were thus smooth ("staple") and monodispersed. We studied specimens with three different combinations of size and shape: round bars about 8 mm in diameter and about 80 mm long and rectangular bars about 95 x 12 x 5 and 56 x 10 x 10 mm in size. The elastic characteristics were determined in an "Elastomat" apparatus [1,2].

The accuracy of determination of the dynamic modulus of elasticity in this apparatus was satisfactory; the deviations from the average value did not exceed ±5% for different specimens of the same production batch having the same porosity. The moduli of elasticity were the same (given identical production conditions) for rectangular and round specimens. In addition to the modulus of elasticity, we determined the ultimate tensile strength σ_b, using flat specimens. This article presents averaged data obtained by testing three specimens per point.

The use of round specimens for testing the modulus of elasticity has a material drawback associated with the need for machining by cutting. As a rule, such machining can be carried out without special plastic impregnation only at relative densities of no less than 45-50%. Preliminary plastic impregnation must be employed for cutting specimens with lower densities and this is inevitably associated with a rise in the modulus of elasticity E. Rectangular specimens do not need to be cut and therefore do not require plastic impregnation. The modulus of elasticity can consequently be determined in rectangular specimens of any porosity without distortion of its value.

The concept of the contact cross-section of porous bodies was introduced in previous articles [3,4]. It is characterized by the nondimensional ratio of the area of the cross-section perpendicular to the applied stress and passing completely through the area of interparticle contact to the total cross-sectional area of the body in this direction. It has been established [3-6] that:

$$\frac{E}{E_c} = \alpha; \quad \frac{\sigma_b}{\sigma_{bc}} = \alpha = \frac{E}{E_c}; \quad \sigma_{bc} = \sigma_b / \alpha = \sigma_b E_c / E,$$

where \(\alpha\) is the nondimensional contact cross-section and \(E, \sigma_b\) and \(E_c, \sigma_{bc}\) are the modulus of elasticity and ultimate tensile strength of the porous and compact nonporous materials respectively (\(\sigma_{bc}\) is also the contact ultimate strength, i.e., a quantity related to the area of the contact cross-section).

The validity of Eq. (1) can be verified experimentally by checking the agreement between the values of \(\sigma_{bc}\) calculated from it with experimental values of \(\sigma\) and \(E\) for materials of appropriate porosity and the figures for the ultimate strength of these same materials in the compact nonporous state. Such agreement has been experimentally established for porous powdered materials [5,6]. It can thus be assumed that the modulus of elasticity for powdered materials is the basic characteristic for determination of the contact cross-section and evaluation of their strength. An experimental study of the validity of this hypothesis for porous fibrous metals was one of the purposes of the present work.

Table 1 presents data on the relationship among the relative density \(\delta\), the modulus of elasticity \(E\), the ultimate tensile strength \(\sigma_b\), the contact cross-section \(\alpha\), and the contact ultimate strength \(\sigma_{bc}\), calculated from Eq. (1), for fibrous copper (preliminary settling in glycerin, pressing, and sintering at 980° for 3.5 h).* It was assumed that \(E_c = 13,000 \text{ kg/mm}^2\) for compact nonporous copper. Table 1 also gives the...

*All the specimens were sintered in a hydrogen atmosphere; the specimens of Kh18N9T steel were sintered in specially purified hydrogen. The hydrogen was freed of oxygen and water vapor by passing it through a device containing platinized asbestos, phosphorus pentoxide, and silicagel. Traces of oxygen (produced by...
values of power $m$ in the formula:

$$\alpha = E/E_C = \theta^m.$$  

(2)

The values of $E$ were determined with round specimens about 80 mm long and 8 mm in diameter. The specimens were cut without plastic impregnation. As was indicated above, the value of $\sigma_b$ was determined with flat specimens. It can be seen from Table 1 that the values of $\sigma_{bc}$ calculated from Eq. (1) were 22-26 kg/mm$^2$, i.e., agreed with the ultimate strength of the nonporous compact copper after pressure-working and annealing.

Figure 1 shows the relationship among the modulus of elasticity $E$, the contact cross-section $\alpha$, and the power $m$ in Eq. (2) for rectangular bars $95 \times 12 \times 5$ mm in size fabricated from copper wire 50 $\mu$m in diameter (sintering temperature $-1000^\circ$, holding time $-4$ h). The value of $m$ passed through a maximum at a density of about 60%.

Figure 2 shows the relationship among the same factors and the relative density for bars $56 \times 10 \times 10$ mm in size fabricated from copper wire and sintered at 980$^\circ$ for 4 h. The value of $E$ was somewhat lower at a relative density of about 40% than for sintering at 1000$^\circ$.

Figure 3 shows the relationship among $E$, $\sigma_b$, and $\sigma_{bc} = \sigma_b E_C / E = \sigma_b (21,000/E)$ kg/mm$^2$ for specimens of the same size fabricated from stainless steel and sintered at 1250$^\circ$ for 3 h. The value of $\sigma_{bc}$ was 50-55 kg/mm$^2$, i.e., coincided with the ultimate tensile strength of ordinary annealed nonporous stainless steel with the same composition. The power $m$ in Eq. (2) was about 3.6 for this steel.

The agreement between the values of $\sigma_{bc} = \sigma_b / \alpha$ and those of $\sigma_b$ for compact metals produced from fibrous porous copper and stainless steel enables us to state that, in accordance with Eq. (1), the contact cross-section of fibrous metals ($\alpha = E/E_C$) can be considered a basic characteristic for calculation of strength, as is the case for powdered metals. However, the minimum value of the power $m$ in Eq. (2) was less than 3. As was pointed out in a previous article [7], the lowest value of $m$ for fibrous metals is close to 2. For example, this means that the maximum value of $\sigma_b$ (which corresponds to the minimum of $m$) at $\vartheta = 50\%$ is 12.5\% of the strength of the compact metal for powdered metals and 25\% for fibrous metals (i.e., the strength of fibrous materials is double that of porous materials at the same porosity).

The damping decrement $Q^{-1}$ (the reciprocal of the number of oscillations over which the amplitude decreases by a factor of $e = 2.71828$) was determined from bending oscillations. The damping was very large for long specimens (round specimens about 80 mm long and rectangular specimens about 125 mm long). The scattering of data was therefore very large and, in a number of cases, irregular (e.g., the decrement sometimes decreased when the porosity increased). The damping decrement $Q^{-1}$ was found to be a regular function of the relative density (Fig. 4) for specimens of fibrous copper and stainless steel only at shorter decomposition of the water vapor) were removed from the hydrogen with a combined drier containing ferrochrome, chromium, titanium, and aluminum oxide.