INFLUENCE OF TECHNOLOGICAL PARAMETERS ON THE MECHANICAL PROPERTIES OF NT-50 SUPERCONDUCTING MULTISTRAND CONDUCTORS AT LOW TEMPERATURES

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The development of industrial superconducting multistrand conductors with the optimum electrical and mechanical properties has made it necessary to investigate the influence of various technological factors on their characteristics of strength and plasticity at low temperatures.

In the literature there are a number of works [1-4] devoted to study of the mechanical properties, at low temperatures, of various Ti—Nb-alloy-base conductors. However, there is practically no systematic investigation of the influence of technological parameters on the mechanical properties.

The purpose of this article is to study the influence of thermomechanical working, strand diameter, and space factor on the mechanical characteristics of NT-50 alloy-base superconducting multistrand conductors in the 4.2-300°K range.

Method of the experiment. The offset yield strength $\sigma_{0.2}$, the tensile strength σ_t, and the elongation δ of several nontwisted superconducting multistrand NT-50-alloy-base conductors in a copper matrix differing in thermomechanical treatment, strand diameter, and space factor were investigated (Table 1). Conductors No. 1, 2, and 5 were obtained by the traditional method with the use of hot extrusion and drawing with an intermediate heat treatment after each 60-70% of deformation. Conductors No. 3 and 4 were produced by hydroextrusion with intermediate heat treatment after each 70-90% of deformation and conductors No. 6 and 7 were produced by hydroextrusion without intermediate heat treatments [5].

Table 1 also gives the phase composition of the NT-50 alloy of the investigated specimens determined by x-ray diffraction analysis in filtered Cu radiation on a DRON-2 instrument.

The mechanical properties were determined in uniaxial tension with a constant rate of 1 mm/min in the 4.2-300°K temperature range. The intermediate temperatures were created by injection of liquid helium. The wire samples were fastened the same way as in [1].

Experimental results and discussion of them. The influence of thermomechanical working. Figure 1 presents typical σ—ε strain curves for conductor No. 1. A similar character of curves is observed for conductors No. 2-4, which differ in the method of production and heat treatment.

From this it follows that on all of the σ—ε curves, with the exception of those obtained at 295°K, in the elastic area there are observed two stages having a different slope to the strain axis. As shown in [6], the first stage is caused by elastic deformation of the strands and the matrix and the second by elastic deformation of the strands and plastic deformation of the matrix. Then the point of the bend may be considered as the yield point of the copper in the composite.

Figure 2 presents the temperature relationships of the offset yield strength $\sigma_{0.2}$, the tensile strength σ_t, and the elongation δ of conductors No. 1-4. The value $\sigma_{0.2}^{I}$ designates the yield strength of copper in the composite. At 295 and 77°K the value of $\sigma_{0.2}^{I}$ is close to the values of the yield strength of cold-drawn copper given in [7]. With a reduction in temperature in contrast to the yield strength of pure copper, the yield strength of the copper in the composite drops, which is related to the presence of residual tensile stresses occurring as the result of the difference in the coefficients of thermal expansion of Ti—Nb and copper.

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TABLE 1. Basic Characteristics of the Investigated Conductors

Conductor No.	Method of preparation	Final anneal	Space factor, %	Strand diam. μm	Number of strands	Presence of phases	
						α	ω
1	Drawn	Without annealing	43.1	10	1045	+	—
2	»	At 375°C	43.1	10	1045	+	—
3	Hydroextruded	Without annealing	41.7	10	1045	+	+
4	»	At 375°C	41.7	10	1045	+	+
5	Drawn	Without annealing	18.4	20	361	+	—
6	Hydroextruded	»	19.4	0.2	9.5million	+	+
7	»	»	19.4	0.1	9.5million	+	+

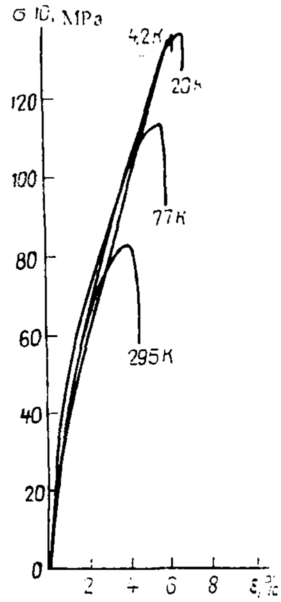

Fig. 1. Strain curves of conductor No. 1 at different temperatures.

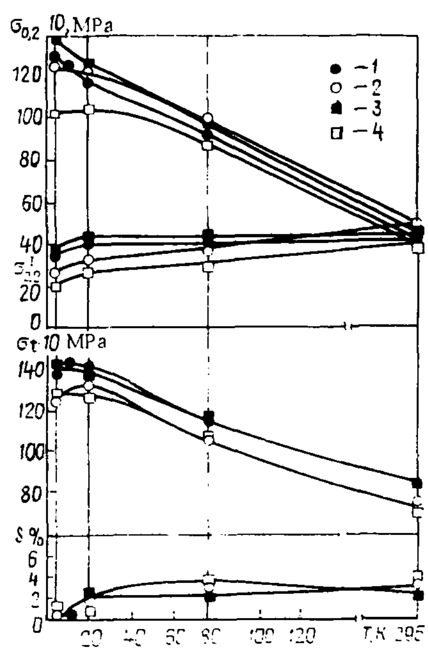

Fig. 2. Temperature relationships of the yield point of the copper in the composite $\sigma^{I}_{0.2}$, the yield strength $\sigma_{0.2}$, the tensile strength σ_t, and the elongation δ of conductors No. 1-4. (Points 1-4 correspond to the numbers of the conductors.)

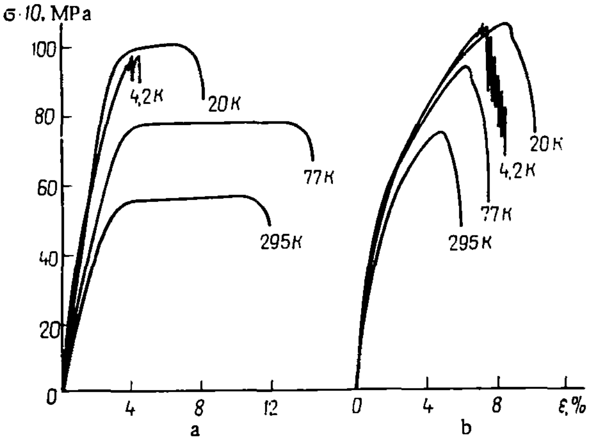

Fig. 3. Strain curves of conductors No. 5 (a) and No. 6 (b) at different temperatures.

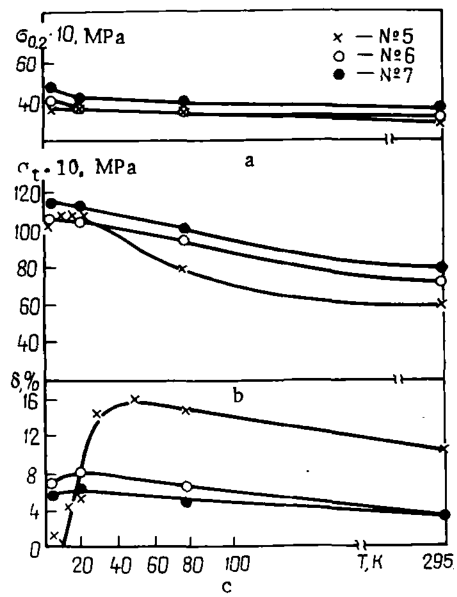

Fig. 4. Temperature relationships of the yield strength of copper in the composite $\sigma^{I}_{0.2}$ (a), the tensile strength σ_t (b), and the elongation δ (c) of conductors No. 5–7.

The yield strength of the conductor may be assumed to be the start of plastic flow of the composite, when the fibers and the matrix deform plastically (third stage of deformation). The values of the yield and tensile strengths of conductors No. 1 and 3, which were drawn with intermediate anneals (conductor No. 1) and hydroextruded (conductor No. 3), are relatively close over the whole temperature range. In contrast to the hydroextruded, the conductor produced by drawing shows some reduction in tensile strength in the 4.2–20°K temperature range. In general, with similar space factors and strand diameters the change in method of production of the conductors does not have a significant influence on their properties.

Heat treatment at 375°C of conductors produced by the two methods (conductors No. 2 and 4) significantly reduces the yield stength in the 4.2–20°K range, while the tensile strength is reduced over the whole temperature range. The reduction in strength may be related to the partial relief of internal stresses in annealing and the increase in the size of the α- and ω-phase particles, which in this case, according to [8], lead to a reduction in the strength properties of the strands of the alloy, especially in the area of low temperatures, where their plasticity drops.

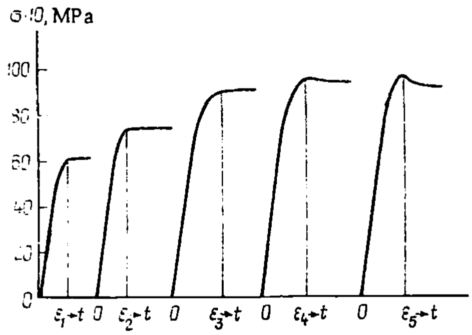

Fig. 5. Stress relaxation in conductor No. 6 at 77°K.

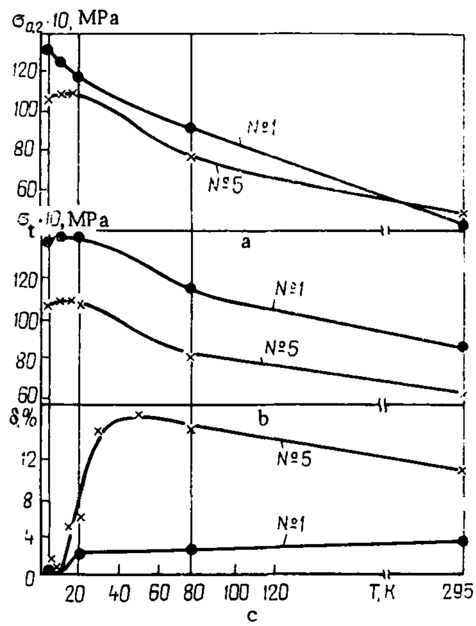

Fig. 6. Temperature relationships of yield strength $\sigma_{0.2}$ (a), tensile strength σ_t (b), and elongation δ (c) of conductors No. 1, 4, and 5.

The temperature relationship of the elongation δ is practically the same for all four conductors and has a tendency toward a reduction in the 4.2°K area. In contrast to conductors with a space factor of ~25% and a strand diameter of ~70 μm [1], heat treatment of conductors with a space factor of ~43% and a strand diameter of ~10 μm does not lead to an increase in plasticity in the 20-300°K temperature range, which is obviously related to the decrease in the role of the copper matrix with an increase in the space factor.

The influence of strand diameter. Figure 3 presents typical σ–ε curves for conductors No. 5 and 6, which differ in strand diameter (~20 and ~0.2 μm, respectively). The strain curves for conductor No. 7 (~0.1 μm) are similar to those for conductor No. 6.

As in the preceding case, on the σ–ε curves for conductor No. 5 there are two portions having a different slope to the strain axis. For conductors No. 6 and 7 there is observed only one linear portion (first stage). The values of the point of transition from the first stage to the second are close for all of the conductors, which makes it possible to assume this point, as in the case of conductors No. 1-4, to be the yield strength of the copper in the composite (Fig. 4).

The second stage of deformation of conductors No. 6 and 7 has a nonlinear character, and from the σ–ε curve, it is not possible to separate it from the third stage, when the strands and the matrix deform plastically. Investigations of the stress relaxation showed that significant relaxation appears with stresses exceeding 2/3-3/4 σ_t (Fig. 5). In the case of loading of individual specimens to this area of stresses, in subsequent unloading a residual deformation of ∿0.3% is observed. Therefore it may be assumed that the area of the strain curves from the transition point to stresses of 2/3-3/4 σ_t is the second stage of deformation (plastic deformation of the matrix and elastic deformation of the strands).

It should be noted that in loading to 2/3-3/4 σ_t the values of residual deformation determined from the σ–ε curve were 1.0-1.2%, while the residual elongation measured on the specimen did not exceed 0.3%. In investigation of longitudinal sections of specimens deformed in this area by methods of optical and scanning electron microscopy, ruptures of the strands were not observed.

Figure 4 presents the temperature relationships of the tensile lengths and the elongations of conductors No. 5-7, which differ in strand diameter. It may be seen that with a change in strand diameter from 20 μm (conductor No. 5) to 0.2 μm (conductor No. 6) the tensile strength increases significantly in the 40-300°K range (by ∿20%) while there is practically no change in it in the 4.2-20°K range. A further decrease in strand diameter leads to a steady increase in strength over the whole temperature range.

The temperature relationship of the elongation changes significantly with a decrease in strand diameter. While for conductor No. 5 (∅ 20 μm) an unsteady relationship is observed with a sharp decrease in elongation in the 9-10°K range similar to that presented in [1], the elongation of conductors No. 6 and 7 steadily increases with a reduction in temperature to 20°K. With a further decrease in temperature to 4.2°K for conductor No. 6 it drops insignificantly (<1%), while for conductor No. 7 it remains practically the same. For both conductors at 4.2°K it is higher than at room temperature.

As follows from Fig. 4, the elongation of conductors No. 6 and 7 in the 20-300°K range is lower than that of conductor No. 5, which apparently is related to the stronger influence of the α- and ω-phase particles in ultrathin strands. At the same time, the elongation of conductors No. 6 and 7 in the 4.2-20°K range is higher than that of conductor No. 5.

Therefore conductors No. 6 and 7 with ultrafine strands (∅0.2 and 0.1 μm) have higher values of strength, a steady change in elongation in the whole temperature range, and higher values of plasticity in the 4.2-20°K range. These conductors have the highest values of density of the critical current, $(2.5\text{-}3)\cdot 10^9$ A/m^2, in a transverse magnetic field of 5 T at 4.2°K.

Consequently, a decrease in strand diameter to 0.1-0.2 μm in conductors with k_s ∿ 19% provides the most favorable combination of mechanical and electrical properties of NT-50-alloy-base superconducting multistrand conductors.

The influence of space factor. Figure 6 presents the temperature relationships of the mechanical properties of conductors with close strand diameters and different space factors. As must be expected, an increase in the space factor leads to an increase in the value of $\sigma_{0.2}$ and σ_t and a decrease in δ. In the 4.2-20°K range the values of elongation practically coincide. The temperature relationships of the mechanical properties in general are similar. The significant decrease in elongation with an increase in the space factor is related to the decrease in the volume of the matrix.

CONCLUSIONS

1. A decrease in strand diameter to 0.1-0.2 μm leads to a steady change in elongation all the way to 4.2°K and to high values of strength.

2. With the same space factors and strand diameters, the influence of the method of production on the mechanical properties of the conductors is insignificant.

3. Heat treatment at 375°C of conductors with a space factor of ∿43% has practically no influence on their plasticity in the 20-300°K range in contrast to conductors with a space factor of ∿25%, which were considered in [1].

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SURFACE STRAIN-HARDENING OF THE BLADES OF GAS-TURBINE ENGINES IN AN ULTRASONIC FIELD

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The blades of gas-turbine engines (GTE) — particularly those blades made of titanium alloys — are very sensitive under variable loads to changes in the properties of the surface layer.

The effectiveness of surface-hardening of GTE blades by surface plastic deformation in an ultrasonic field [1] is determined to a considerable extent by the selection of an optimum regime.

By an optimum regime of surface strain-hardening of GTE blades, we mean a deformation regime which will ensure adequate blade life under alternating loading and help it to withstand shock bending loads occurring in service in the event that foreign objects enter the engine.

To definitively establish an optimum strain-hardening regime, we conducted fatigue tests of alloys VT8 and ÉP718.

The 1.4-mm-thick specimen, with a fillet having a radius of 1.2 mm (Fig. 1), was strain-hardened for 10 min in an ultrasonic field by balls 2.35 and 1.3 mm in diameter. The strain hardening was done in a special ultrasonic device [2] using a wetting liquid.

Fatigue tests of cantilevered specimens were performed on a VÉDS-200 vibrating stand on a base of 10^7 cycles until the appearance of a macrocrack (Table 1).

It can be concluded from analysis of the test results that the greatest effect is seen when alloy VT8 and steel ÉP718 are strain-hardened by 1.3-mm-diam. balls. Strain-hardening alloy VT8 with the 2.35-mm-diam. balls even reduced the endurance limit by 2%.

The increase in the fatigue resistance of the specimens is due to strain-hardening of the surface layer and the formation of favorable compressive residual stresses in it (Fig. 2). The magnitude and sign of the residual stresses was determined on flat specimens measuring 1.4 × 8 × 60 mm with the aid of a PION-2 instrument.

It can be seen from Fig. 2 that strain-hardening with 2.35-mm-diam. balls induces higher-level compressive stresses in the flat specimens than do the 1.3-mm-diam. balls.

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