INFLUENCE OF PULSE CURRENT DURING A SEVERE PLASTIC DEFORMATION ON CRITICAL TEMPERATURE OF NBTI SUPERCONDUCTOR

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Abstract. *The influence of severe plastic deformation by rolling with pulse current on superconducting composite, which consists of electrical and thermal Cu-stabilizer, Nb-diffusion barrier and Nb–47wt.%Ti core, has been investigated. For obtaining the relation between the superconducting critical property of NbTi and pulse current parameters, there were used four different modes of pulse current during the rolling. As a result Volt-temperature characteristic for samples after the rolling was defined. The experimental results highlighted the need for an optimization of the deformation parameters. Based on the results, it was concluded that the rolling with pulse current has the influence on the critical temperature, which, consequently, can assist in the studying of the critical current density improvement in NbTi strands.*

Keywords: *low temperature superconductors; NbTi; pulse current; severe plastic deformation; critical temperature.*

Introduction

It is well known, that low temperature commercial superconductors based on NbTi alloy remain the most widely used materials to produce current-carrying elements of magnetic systems for scientific and industrial applications ranging from medical diagnostic MR-scanners and magnetic separators to a thermonuclear reactor and Test Fusion Tokamak Reactor.

The perspective methods of the current-carrying capacity improvement for superconducting NbTi strands are based on studying of the new “deformation – heat treatment” schemes [1,2]. According to it, the idea about improvement of critical parameters in superconductor strands by one of the well-known deformation method and effect of pulse current instead of heat treatments in the latter stages of production has been developed.

It was shown in [3-5] that carrying out a combined effect of severe plastic deformation by rolling (SPDR) with pulse current of various types of materials leads to a sharp intensification of structure refinement of deformed materials, and also promotes the structure and condition changes of interphase boundaries in microcomposite materials. This thermodynamic feature of electroplastic processes during a microstructure forming allows achieving a sharp intensification of high-dispersed precipitate formation mechanisms in the alloys. It was studied in [6] that pulse current allows obtaining a nanostructure in monofilamentary NbTi strands during the rolling. It was shown that pulse current during the SPDR allows enhancing the strength, microhardness and retains the superconductivity effect. It was found that tension with pulse current displays the electroplastic effect in the NbTi superconductor.

It was studied in [7] that directly after precipitation, critical temperature (Tc) increases. Drawing the wire returns these parameters to their single-phase values. There was also shown, the dependence of critical temperature values for single-phase NbTi as a function of composition.

The effect of equal-channel multi-angle pressing combined with hydroextrusion and drawing followed by thermal treatment on superconducting transition temperature of a multifibre superconducting wire made of Nb + 50 wt% Ti alloy has been investigated in [8].

It has been observed in [7, 9-13], that Tc at zero external magnetic field is usually equals 8,9-9,4 K.

In an attempt to improve understanding between the SPDR with pulse current process and the critical superconducting characteristics, the first results of the investigation on multifilamentary NbTi strands are presented.

Materials and methods

Specimens have been obtained from NbTi wires originally produced by Chepetsky mechanical factory (TVEL Corporation, Russia). The specimens were multifilamentary Nb–47wt.%Ti alloy-based rods with a diameter of 7 mm and a length of 120 mm. SPDR with pulse current was conducted on a rolling mill with calibrated rollers. The caliber size was varied from 1 to 7 mm. The rolling mill was equipped with a pulse current generator. Current was provided to the deformation zone using a sliding contact (negative pole) of the specimen and one of the rolls (positive pole). SPDR was carried out step-by-step on the 4 rods under pulse unipolar electric current with a speed of 50 mm/s, a pulse duration of 120×10^{-6} s, frequency of 1000 Hz and current density j = 0-100 A/mm^2. The rolling was performed at the room temperature. After each step, the samples were cooled in water to avoid heating. The bar was turned 90° along the longitudinal axis and the rolling direction changed to the opposite direction before each subsequent pass. True strain $e = \ln S_0/S$ (S_0 and S are cross-sectional squares of the rod before and after rolling, respectively) after rolling was 3.4 (Ø 1 mm).

In Table 1, the SPRD parameters with and without pulse current of the samples to diameter of 1 mm are presented.

Table 1. Parameters of SPRD with and without pulsed current

Sample	Current density, j, A/mm^2	Pulse duration,10^{-6} s	Frequency, Hz	Rolling speed, mm/s
#1	0	0	0	50
#2	25	120	1000	50
#3	50	120	1000	50
#4	100	120	1000	50

The critical temperature on the samples by size Ø 1x 50 mm after SPDR with different pulse current density was defined. All the rolling samples were annealed at 250 ^{o}C during 15 minutes. Measurements of critical temperature were carried out at Bochvar Institute (VNIINM, Russia) by a standard four-contact method, on a DC with a current density about 1 A/mm^2. The measuring probe with a sample was located in the camera of variable temperatures (CVT) supplied with the coal TSU thermometer and the 50 W heater. After CVT filling with heat exchange gas (helium) and CVT cooling in liquid helium before achievement of NbTi by a sample of a superconducting state, which was fixed on lack of electric resistance, sample temperature slowly increased at the expense of a current transmission via the heater. In the field of transition of a sample to a superconducting state the Volt-temperature characteristic (VTC) was fixed.

Results and discussion

On Figure 1, VTC of four samples are given in relative coordinates on an axis Y for convenience of results comparison.

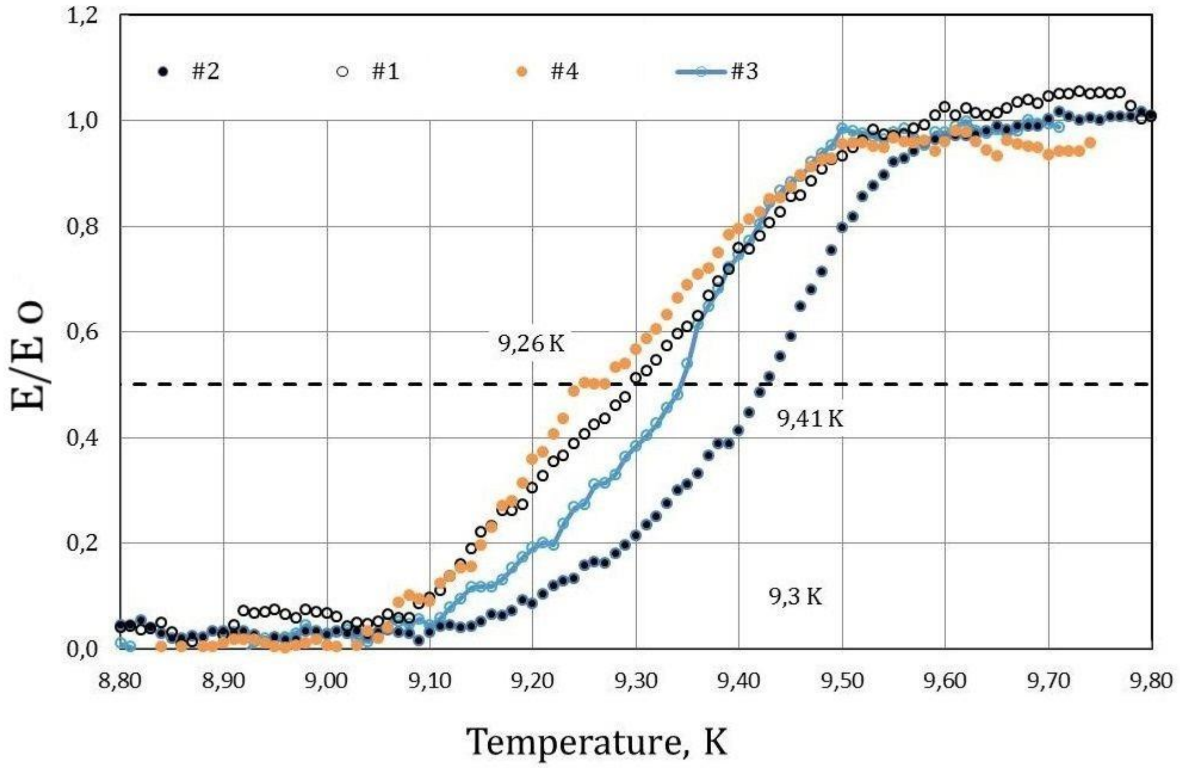

Fig. 1 Volt-temperature characteristics of samples in the zero external magnetic field after SPDR: #1 – without pulse current; #2 – with j=25 A/mm^2; #3 – with j=50 A/mm^2; #4 – with j=100 A/mm^2.

On the graph dashed line designated the middle of superconducting transition, and points noted the measured results for each sample.

From Figure 1, it is visible that the beginning of transition to a superconducting state is carried out at a temperature of 9,6-9,5 K.

The measured values of critical temperature are presented in Table 2 for all studied samples in points of the beginning (Tc_n), the middle (Tc_m) and the end of transition (Tc_s).

Table 2. Critical temperatures in zero external magnetic field for SPRD samples

Tc, K	#1	#2	#3	#4
Tc_n	9,52	9,6	9,5	9,5
Tc_m	9,3	9,41	9,34	9,26
Tc_s	9,07	9,1	9,1	9,05

The results show that the resistive transitions are all about 0.5 K wide. Value of Tc at the level of 9,5-9,6 K indicates the presence of α-Ti precipitates. The Tc_m values correspond with standard measurements [7, 9-13] and according to dependence of the measured critical temperature on α-Ti precipitate separation in [7], the proximity of the normal conducting precipitates from 7 to 10 nm can be assumed. The width of the transitions presents an inhomogeneity in the material. It can be connected with an irregularity of α-Ti phase in the course of rolling mill with calibrated rollers and influence of high pulse current density during the rolling, by analogy to similar influence of heat treatment in [11].

Based on data in Table 2, the dependence of critical temperature on pulse current density, which was used during the SPDR, is shown in Figure 2.

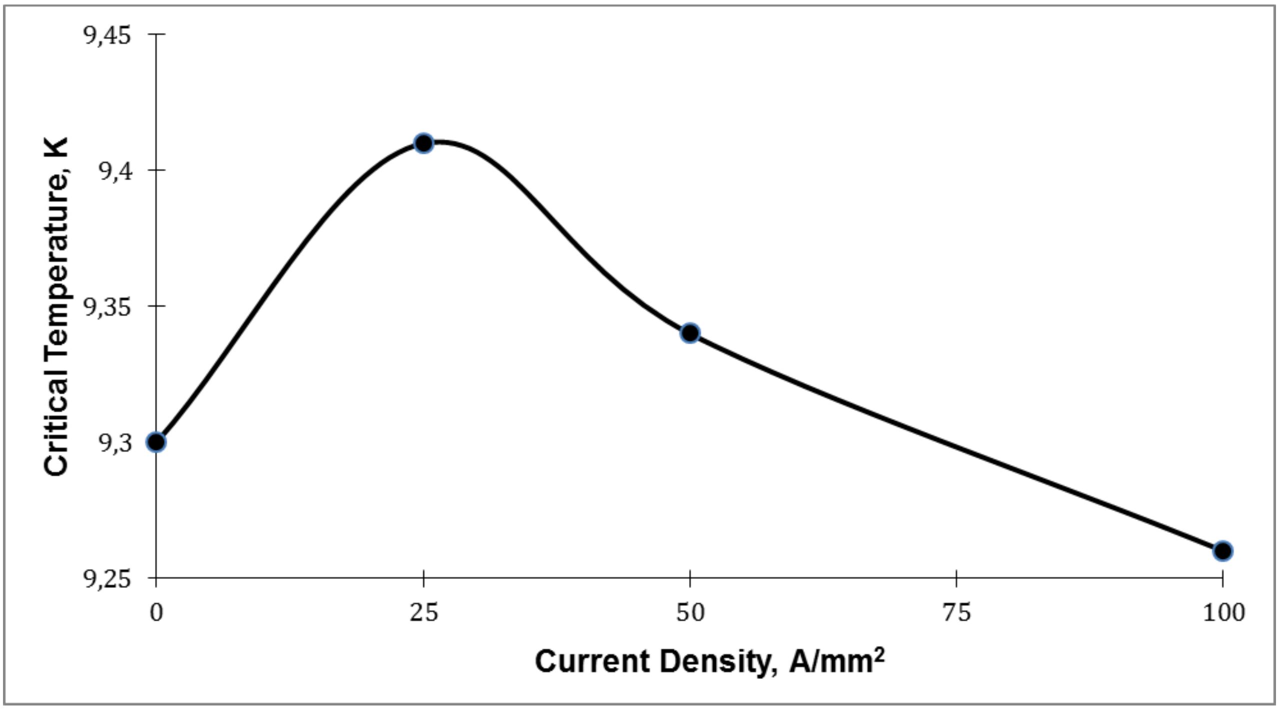

Fig.2 Dependence of the critical temperature on the pulse current density

The curve behavior on Figure 2 represents the increase in critical temperature values with a peak at j=25 A/mm^2 and the decrease after that. Therefore, the quantity of the α-Ti precipitates is higher, than after cold rolling without pulse current and SPRD with another current density. As it has been shown in [7], the decline in Tc is related with decreasing precipitate thickness and separation. According to this fact, as we believe, more uniform structure in sample #4 with less precipitate thickness and precipitate spacing in comparing with the other samples was obtained.

Conclusions

In this study, the severe plastic deformation by rolling (SPDR) with pulse current applying to multifilamentary Nb–47wt.%Ti alloy-based rods was performed. Tc was measured in a two-phase Nb-Ti strands as a function of the different current densities during the rolling. The Tc corresponds to standard references values. The maximum critical temperature is attained under the deformation with 25 A/mm^2 current density. Although, more stabilized strand was processed by SPDR with 100 A/mm^2 current density. The results support the idea that applying of pulse current during the SPDR has an influence on the different materials, including NbTi superconductors. The dependence of critical superconducting characteristics on pulse current parameters during the SPRD will be studied in the future.

Acknowledgments

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