25th International Cryogenic Engineering Conference and the International Cryogenic Materials Conference in 2014 (ICEC 25–ICMC 2014)

Deformation behaviour and Tc of NbTi superconductor processed by cold rolling with a pulsed current

Anna Frolova, Vladimir Stolyarov*

Mechanical Engineering Research Institute of the Russian Academy of Sciences ,Moscow, Russia; *anna.frolova.ras@gmail.com

Introduction

NbTi superconductors are traditionally produced by a process, which comprises many stages. It is characterized by large true strain, as well as high energy, labor and time consumption. The combined effect of severe plastic deformation by rolling (SPDR) and the pulse current of various types of materials leads to a sharp intensification in structural refinement of deformed materials, a decrease in flow stresses, as well as to improvement of the deformability, microhardness, and other mechanical characteristics of the material. It is assumed that these effects are due to the interaction of conduction electrons with lattice defects during material deformation. 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 was developed in this study. The aim of this study is to investigate specific features of SPDR with pulse current in NbTi superconductive wire.

Conclusions

In this study, SPDR with pulse current applied to multifilamentary Nb–47wt.%Ti alloy-based rods was performed. The Tc corresponds to standard reference values. The maximum Tc was attained under deformation with 25 A/mm^2 current density. Although a more stabilized strand was processed by SPDR with 100 A/mm^2 current density. The highest microhardness and ultimate strength was obtained with SPDR with 50 A/mm^2 current density and equalled 4655 MPa and 936 MPa, respectively. The results suggest that application of pulse current during SPDR has an influence on the different materials, including NbTi superconductors, but it also highlights the need for optimization of the deformation parameters.

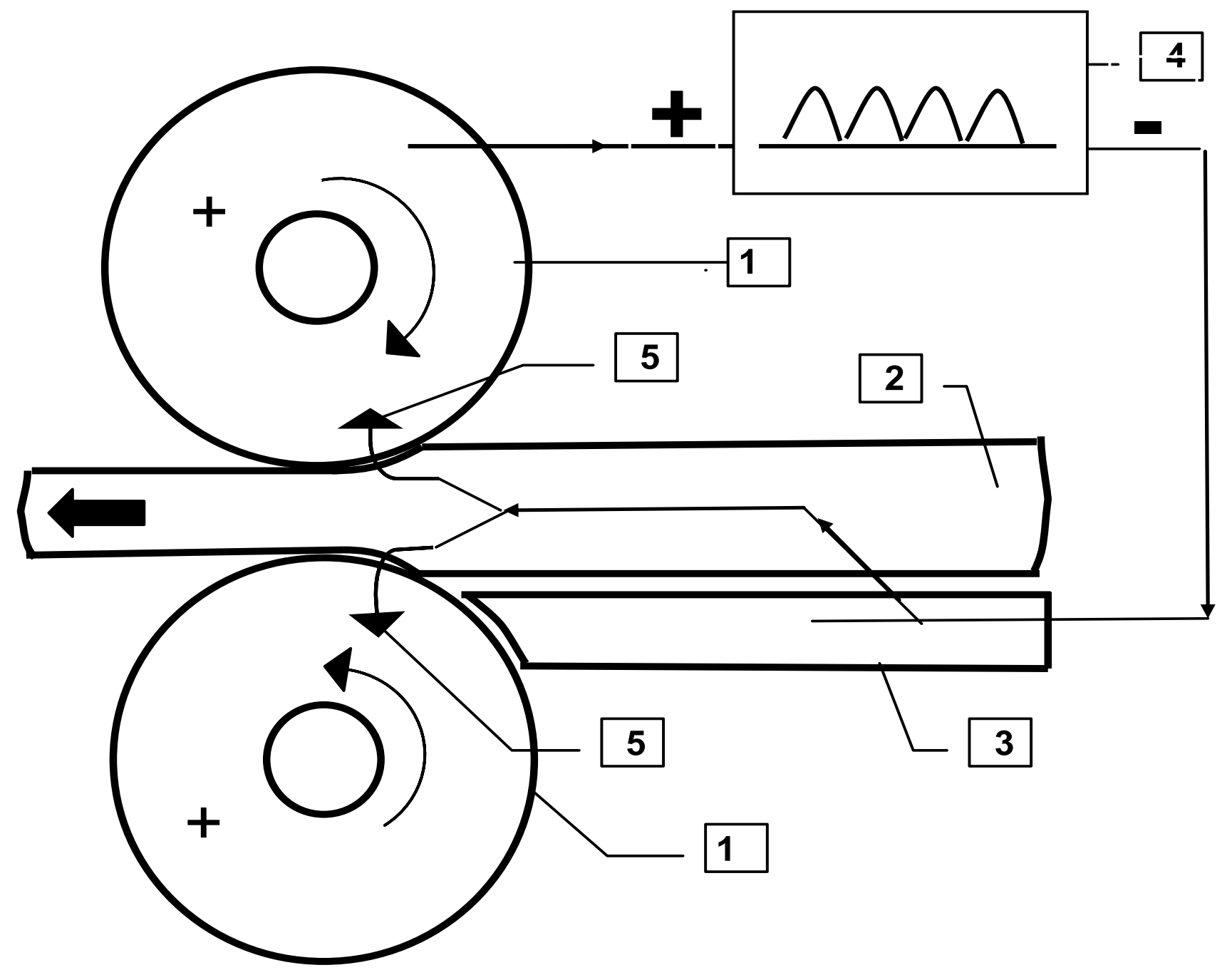
Materials and Methods

Material

The specimens were multifilamentary rods which consisted of electrical and thermal Cu-stabilized matrix and Nb–47wt.%Ti-based filaments, with a diameter of 6 mm and a length of 120 mm .

Experimental Procedures

Pulse current supply scheme in SPDR:



SPDR with pulse current was conducted on a rolling mill with calibrated rollers. The caliber size varied from 7 to 1 mm. The rolling mill was equipped with a pulse current generator (4). Current was provided to the deformation zone with a sliding contact (negative pole) (3) of the specimen (2) and one of the rolls (positive pole) (1). SPDR was carried out step by step on the four rods under pulse unipolar electric current (5 - current direction) with a speed of 50 mm/s, 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 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 after rolling was e=3.4 (Ø 1 mm).

The critical temperature of samples measuring Ø 1x 50 mm after SPDR with different pulse current density was defined . All the rolling samples were annealed at 523 K for 15 minutes. Measurements of critical temperature were carried out at Bochvar Institute (VNIINM) by a standard four-contact method, on a DC with a current density of about 1 A/mm^2.
In the transition of samples to a superconducting state the volt-temperature characteristics (VTC) were determined (Figure 1).

Microhardness of the samples was measured on a PMT-3M device at loading of 0.05 N and maintained for 15 (± 2) seconds . The relative error of measurements was 8%.

Nanoindentation was performed on a nanoindentation tester (NHT) at loading of 0.001 N (the imprint side was about 630 nm). The relative error of measurements was 4%.

The ultimate strength of wire 1 mm in diameter and 50 mm long was estimated by tensile tests, which were conducted by a tensile test machine of the IR 5081-20 type. The relative error of measurements was 6%.

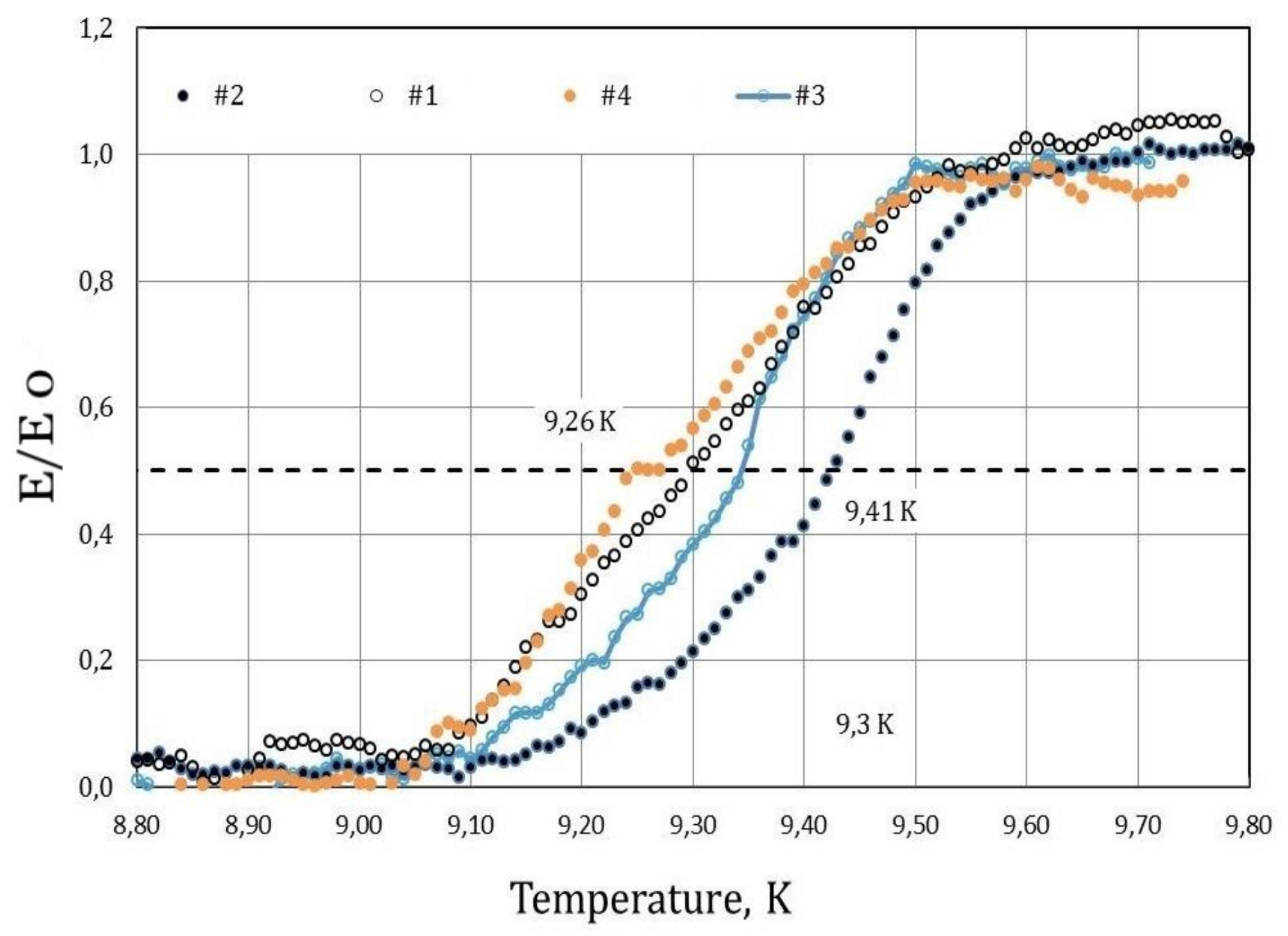


Fig. 1. Volt-temperature characteristics of samples in the zero external magnetic field after SPDR: #1 – without pulse current; #2 – with j=25 A/mm^2; #3 – with j=50 A/mm^2; #4 – with j=100 A/mm^2.

Results

Mechanical Characteristics

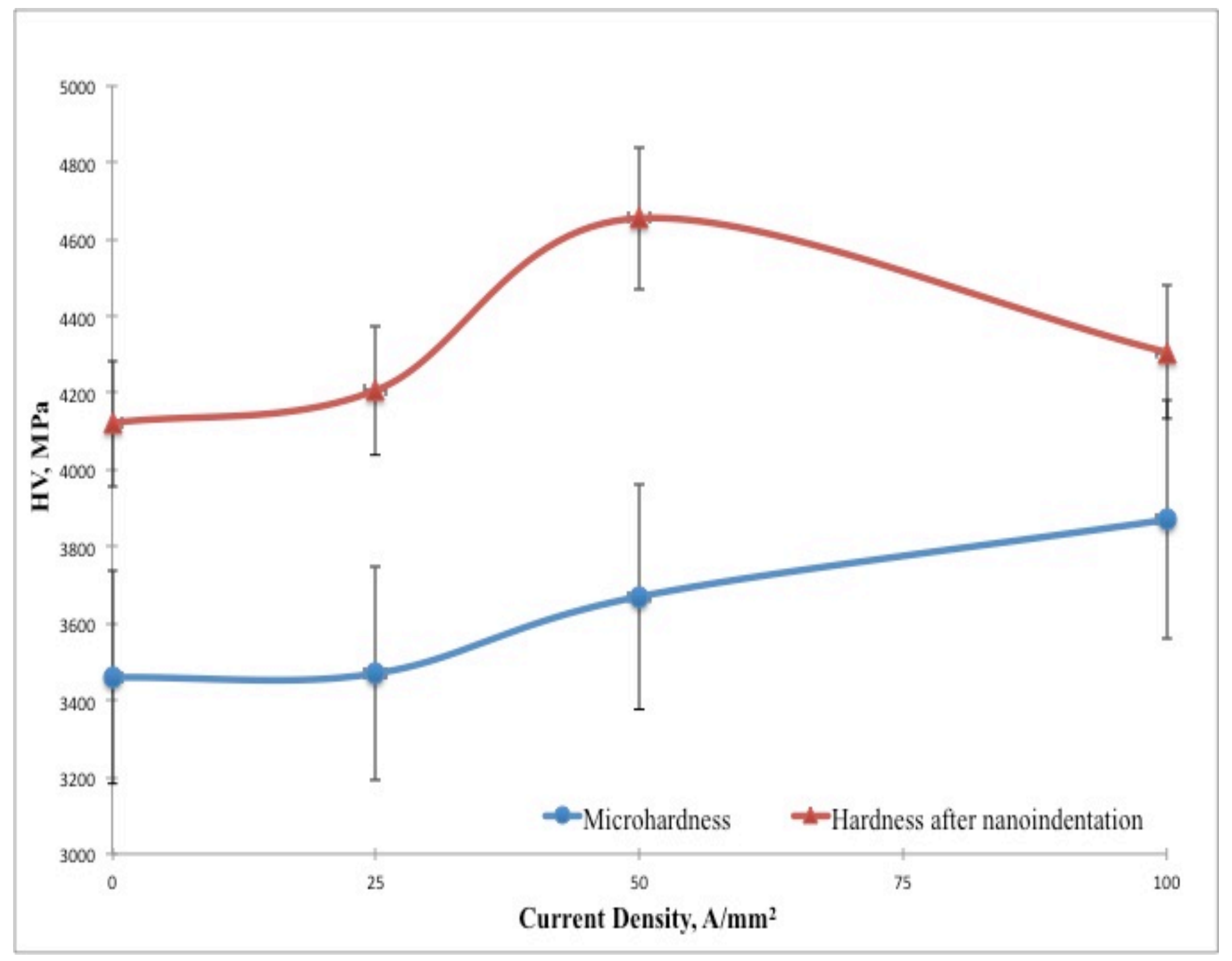


Fig.2 Dependence of microhardness and hardness after nanoindentation on pulse current density (e=3.4)

Figure 2 illustrates the dependence of hardness on the current density with which samples were rolled (e= 3.4). Increase of microhardness can be connected with strain hardening, allocation of finely dispersed secondary α-Ti phase precipitations and increase of crystal defects in the structure.

Strain hardening and allocation of α-Ti precipitations, as in the case with microhardness, may explain the gradual increase of hardness after nanoindentation. Softening is probably connected with possible change of alloy structure, namely partial dissolution of the phase α-Ti as a result of sample heating during rolling with high current density. It also can be connected with partial loss of hardening at the interaction of pulse current with defects in the crystal lattice of the material.

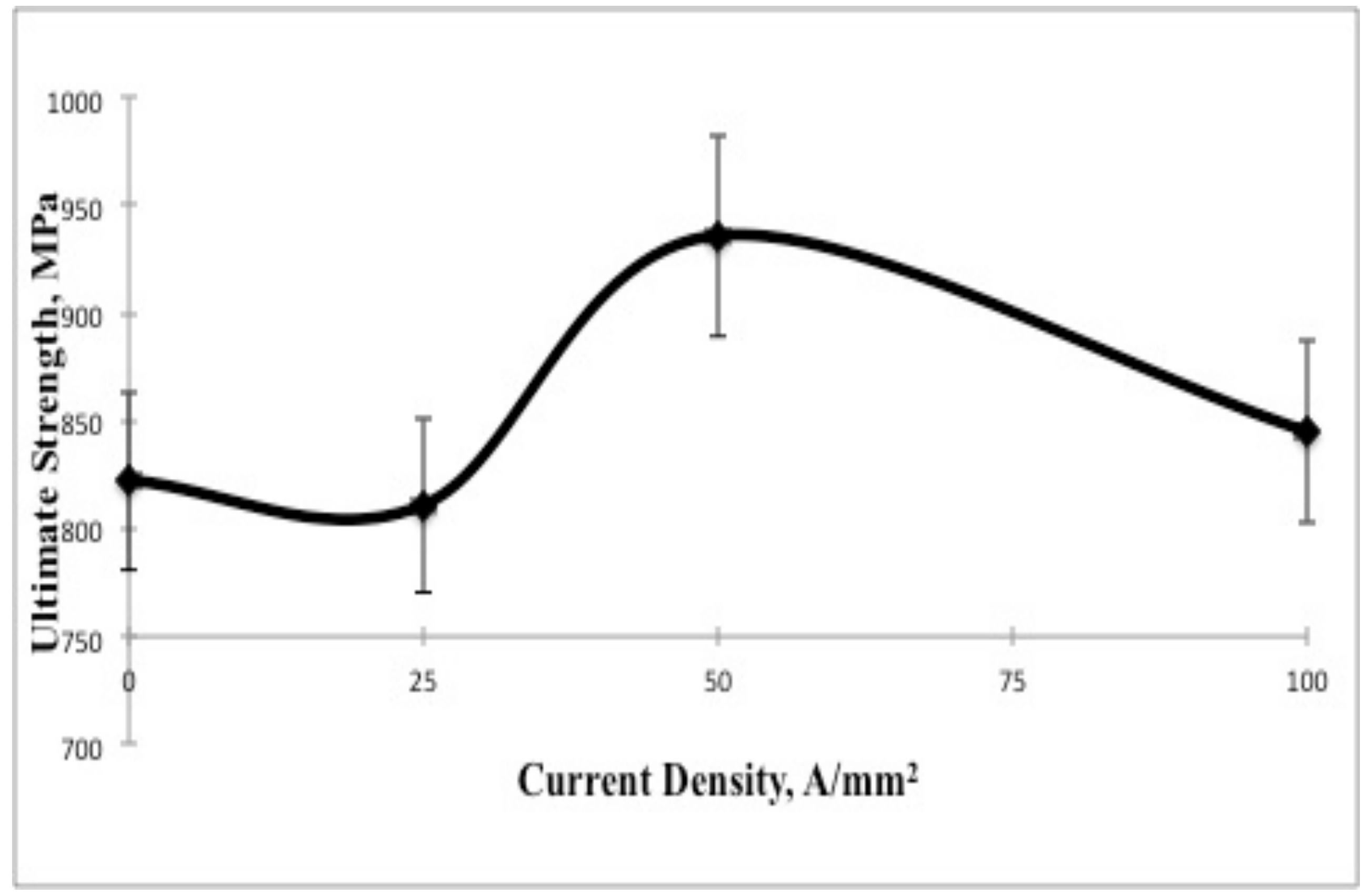


Fig.3 Dependence of ultimate strength on pulse current density (e = 3.4)

Tensile tests of wire samples showed that, as the current density during the rolling varies, the ultimate strength of the composite is highest at SPRD current density j= 50 A/mm^2 (Figure 3). The curve behavior correlates with the behaviour of hardness after nanoindentation. This peculiarity can be explained by the noted mechanism in the dependence of hardness on current density.

Critical Temperature

The dependence of critical temperature on pulse current density, which was used during the SPDR, is shown in Figure 4. The value of Tc at the level of 9,2 to 9,4 K indicates the presence of α-Ti precipitates. The curve behavior 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. The decline in Tc could be related to decreasing precipitate thickness and separation. A more uniform structure in sample #4 with less precipitate thickness and precipitate Spacing than the other samples was obtained .

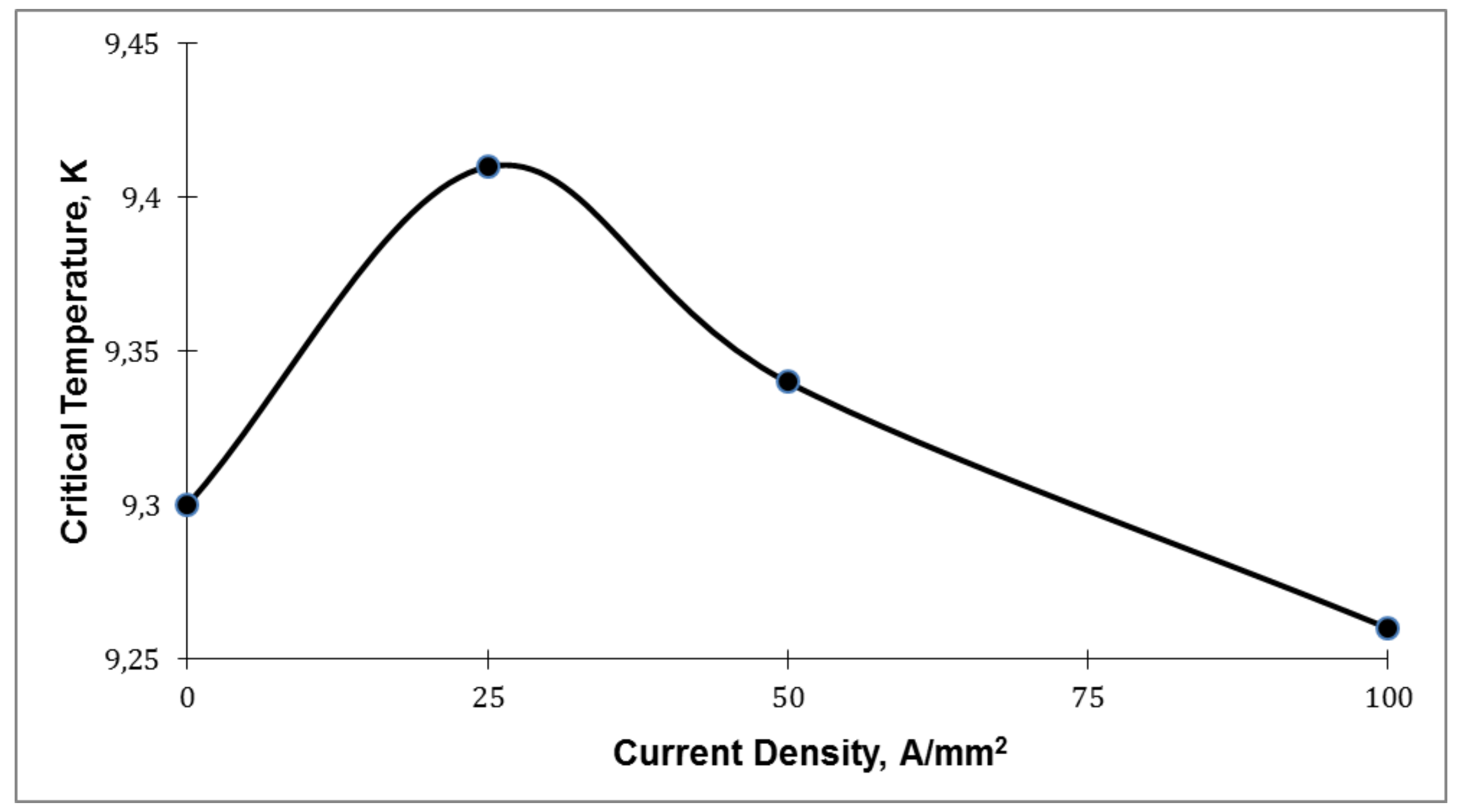


Fig. 4 Dependence of the critical temperature on the pulse current density