IOP Conf. Series: Materials Science and Engineering **731** (2020) 012006 doi:10.1088/1757-899X/731/1/012006

The Effect of Plastic Deformation on the Geometric Parameters of Nb-Ti-Based Superconducting Cable

A Yntymakova[1,2] and G Shlyakhova[2]

[1]National Research Tomsk Polytechnic University, Tomsk, Russia
[2]Institute of Strength Physics and Materials Science SB RAS, Tomsk, Russia

E-mail: aklima.int@mail.ru

Abstract. The current carrying capacity of a superconductor depends on its microstructure, that is, the shape, size and volume content of particles released during the decomposition of a solid solution. At the technological stage, it is necessary to ensure continuity of the process and a given density of micro defects. Therefore, the aim of this work was to assess and present the results of studies of the effect of plastic deformation (tension) on the structure of a multicore superconductor based on Nb-Ti alloy. Mechanical tests were carried out for uniaxial tension to failure on a Walter + Bai AG LFM-125 testing machine (maximum force up to 125 kN). The internal structure of the sample at the fracture site after the sample preparation was studied using a Neophot-21 optical microscope. The effect of deformation on the geometric parameters of Nb-Ti fibers was studied. Sample preparation included thin sections, polishing and etching.

1. Introduction

Superconductivity is one of the most outstanding discoveries of the twentieth century and lies in the ability of certain substances to conduct electricity without resistance at very low temperatures, that is, become superconductors [1-2]. The critical temperature of the superconductor based on Nb-Ti alloy is 9.8 K, the critical field is 12 T. The most important applications of superconductors are the creation of strong magnetic fields, generation and transmission of electricity. A solenoid made of a superconducting material can work without supplying energy from outside, until at some point in its life the solenoid valve fails and stops working.

Maintaining a solenoid in a superconducting state does not require large energy costs. With zero resistance, the problem of heat dissipation is easily solved. In addition, superconducting magnets are much more compact than usual. Each kilogram of the mass of the superconducting magnet creates a magnetic field equivalent in strength to the field of a 20-ton electromagnet with an iron core.

The problems of thermonuclear energy cannot be solved without the use of powerful superconducting magnets. To carry out controlled thermonuclear fusion of helium nuclei from deuterium and tritium nuclei, it is necessary to maintain hot tritium-deuterium plasma heated to 10^8–10^9 °C in the reaction space. Only superconducting magnets can create fields of this force. Superconductors are used to produce magnetic fields with large induction. For example, superconducting alloys with large critical inductance are used to make wire for transformer windings. High-density current is generated in such windings and the electromagnet has a magnetic field of great strength. The induction of the resulting fields reaches 10 T. Alloys and compounds of niobium become superconducting at sufficiently high temperatures. They can withstand fairly strong magnetic fields and are characterized by a high current density. In liquid helium with an external field with an induction of 2.5 T, the critical current density for Nb-Ti is 2.5 kA / mm^2 [3-4].

2. Materials and methods of research

Mechanical tests for uniaxial tension to failure were carried out on two identical samples ø 1.3 mm on a Walter + Bai AG LFM-125 testing machine (maximum force up to 125 kN). An example of a sample in its initial state is shown in Figure 1, a cross sectional image was obtained using Neophot-21 optical microscope with 100x magnification [5]. As shown in the figure: the cable consists of a Cu sheath, a Cu matrix and about 3,500 Nb-Ti fibers located between them and each fiber is in the niobium barrier. Niobium barriers serve to prevent the diffusion of the Nb-Ti alloy into the stabilizing copper sheath and the occurrence of stray currents. All Nb-Ti strands have round-shaped cross section and the following chemical composition: 35.66 at. % Nb and 63.07 at. % [6-10].

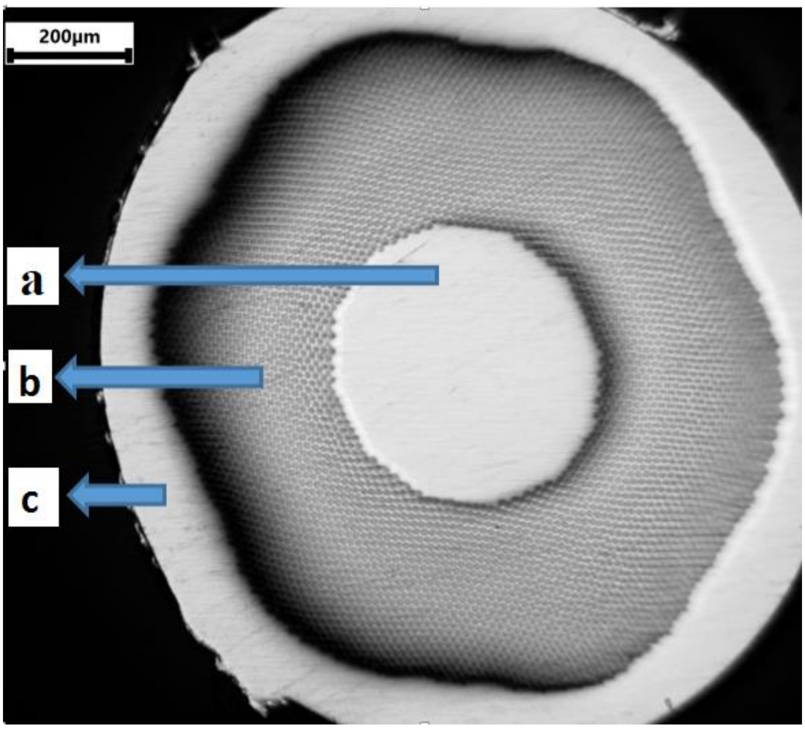

Figure 1. Cross sectional image obtained in the initial state: (a) copper matrix, (b) Nb-Ti fibers, (c) copper sheath.

Figures 2 and 3 show diagrams of tensile specimens during mechanical tests for uniaxial tension to failure on a testing machine. Figure 2 shows a diagram of a sample with a strain of ε = 3.4 % the elongation at break was 1.79 %; the fracture necking was 2 %. For the sample with strain ε = 4.3 % the elongation at break was 2.21 %; the fracture necking was 2.50 %.

IOP Conf. Series: Materials Science and Engineering **731** (2020) 012006 doi:10.1088/1757-899X/731/1/012006

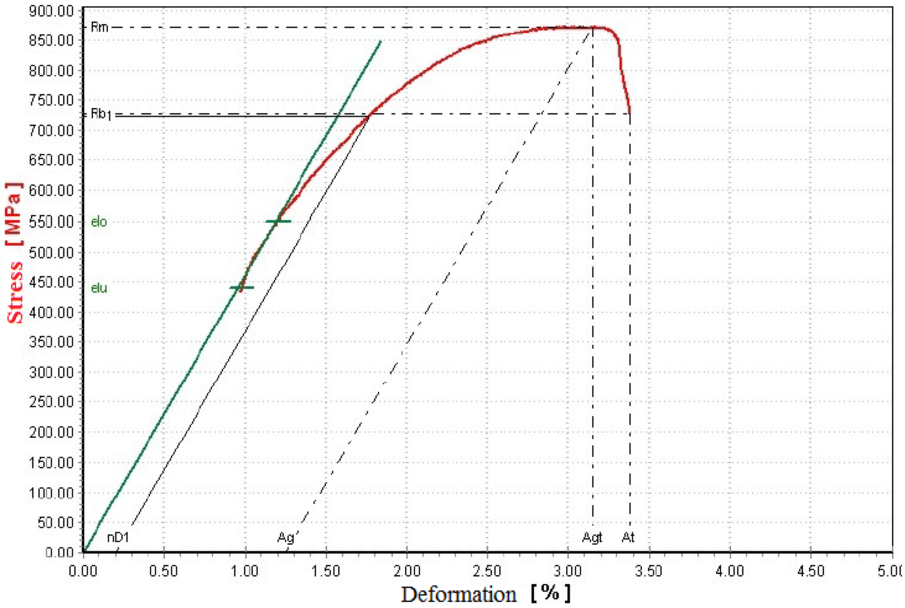

Figure 2. Fracture deformation: 3.4%; the green line indicates the elastic limit, the red line indicates the irreversible deformation.

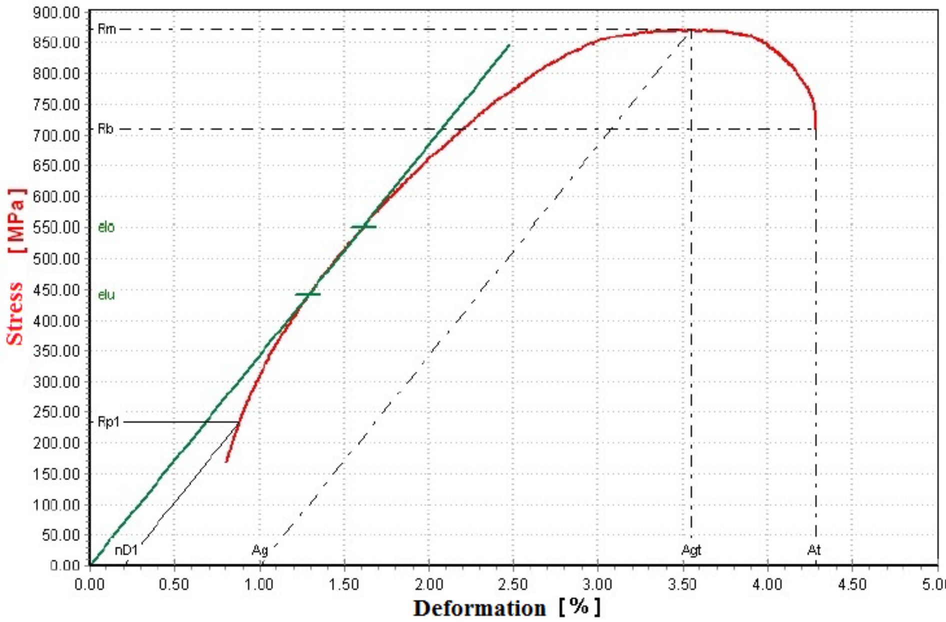

Figure 3. Fracture deformation: 4.3%; the green line indicates the elastic limit, and the red line indicates the irreversible deformation.

3. Results

To study the structure of the superconductor after tensile tests, metallographic thin sections were prepared according to standard procedures for these alloys [11]. Finally, thin sections were etched with reagent [12].

Figures 4 and 5 show images of the structures of the samples after breaking at various degrees of deformation $\varepsilon = 3.4$ % and $\varepsilon = 4.3$ %. The influence of deformation on the geometric parameters was studied and the increase in the deformed fibers from the copper core to the shell was calculated: the

IOP Conf. Series: Materials Science and Engineering **731** (2020) 012006 doi:10.1088/1757-899X/731/1/012006

region of deformed fibers in the sample with deformation ε = 3.4 % was 35 %, in the sample with deformation ε = 4.3 % it was 58.5 %. Images were obtained using an optical microscope Neophopt-21 with 500x magnification.

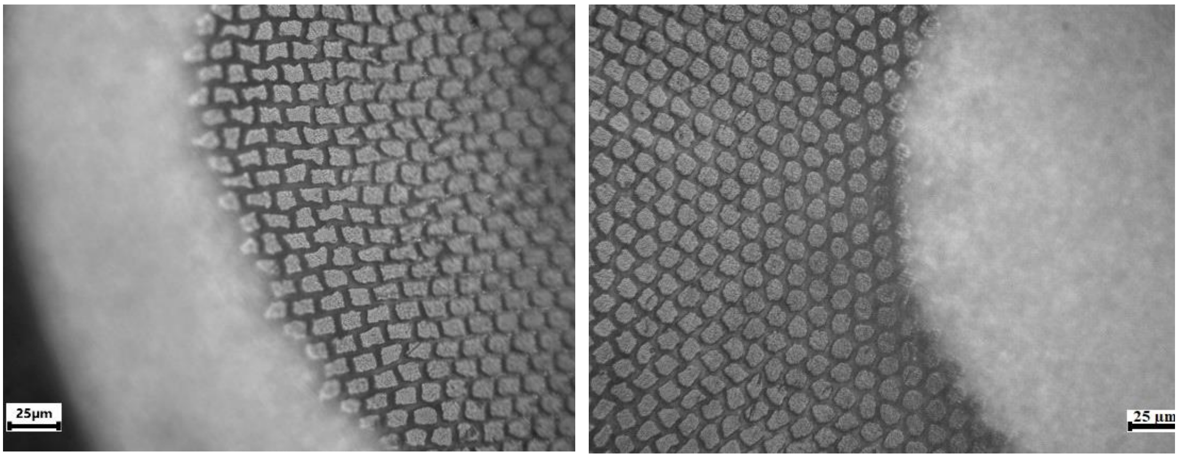

Figure 4. Sample with ε = 3.4%. The region of the located fibers from the matrix to the cable sheath is 335 µm.

As can be seen in the panoramic figures, in the region of the copper shell of the sample, Nb-Ti fibers had an elongated square or rectangular shape. This deformation of the fibers is explained by the load on the fibers under tension precisely on the edges of the sample. Moreover, in the region of the copper matrix, the fibers had a less deformed round shape. In the initial state, the regular shapes of the fibers are round.

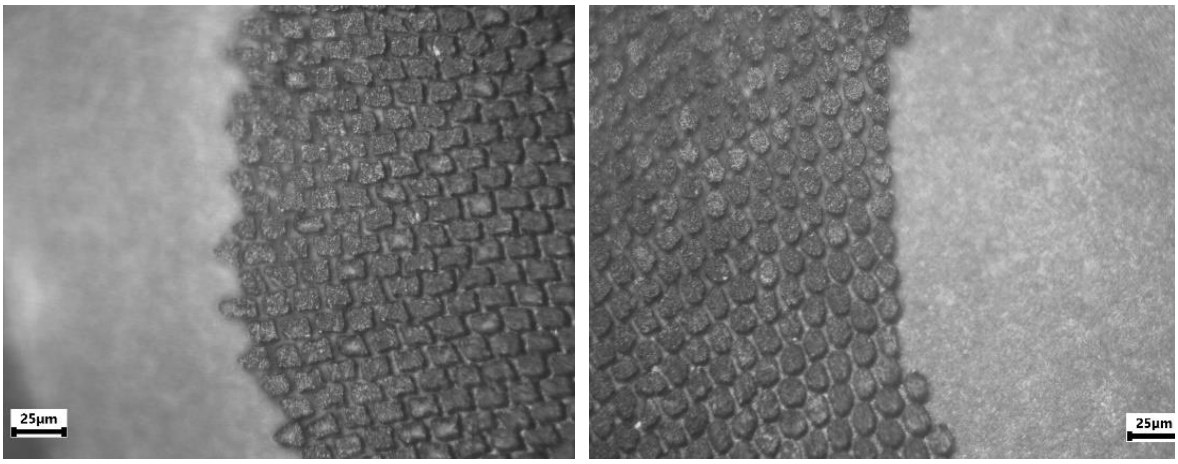

Figure 5. Sample with ε = 4.3%. The length of the fibers located from the matrix to the cable sheath is 350 µm.

4. Conclusion

After studying the sample it was found that for the same tensile strength (R_m = 873 MPa) for samples with ε = 3.4 % and ε = 4.3 %, the elongation (δ) upon failure turned out to be different and amounted to ≈1.8 % and 2 %, respectively.

The studies showed that for the sample with deformation ε = 3.4 % the region of deformed fibers from the matrix to the cable sheath was 35 %, while for the sample with deformation ε = 4.3 % the region of deformed fibers from the matrix to the cable sheath was 58.5 %. These results evaluate the effect of plastic deformation on the geometric parameters of the sample.

Future aspect of this investigation is very useful for industrial applications and can be used in further research work.

Acknowledgments
This work was performed as part of the Fundamental Research Program of the State Academy of Sciences for 2013–2020, line of research III.23.

References

[1] Bardeen J, Cooper L N and Schrieffer J R 1957 *Theory of superconductivity (*American Physical Society) p 1175–1204
[2] Kalimov A G 2007 Physical foundations of *superconductivity J. St. Petersburg: RADIO AND COMMUNICATIONS* 344-52
[3] Shikov A V 2003 The development of superconductors for the ITER magnetic system in Russia *J. Non-ferrous metallurgy* 1
[4] Soloviev V 2017 International Thermonuclear Reactor (ITER) *J. Spacegid (Electronic Materials)*
[5] Vlasov A I, Elsukov K A and Kosolapov I A 2011 *Optical Microscopy* A Training Manual. Publishing House of MSTU named after Bauman N E p 184
[6] Lee P J, Larbalestier D C and McKinnel J C High titanium 1988 Nb-Ti alloys initial microstructural studies *Adv. Cryog. Eng. Mat. 34* p 967-74
[7] Cherny O V, Andrievskaya N F and Ilicheva V O 2002 The microstructure and critical current density of Nb-48 wt.%Ti superconductor with very high alpha-Ti precipitate volume and very high critical current *Adv. Cryog. Eng. 48B (2002)* p 883-90
[8] Cherny O V, Storozhilov G E and Andrievskaya N F 2005 Structure and properties of differently directed deformed niobium-titanium alloy *IEEE Trans. Appl. Supercond.* 15 p 3502-05
[9] Zuev L B, Shlyakhova G V, Barannikova S A and Kolosov S V 2013 Microstructure of elements of a superconducting alloy Nb-Ti cable *Russ. Metal* p 229-34
[10] Zuev L B, Shlyakhova G V, Barannikova S A and Malinovskiy A May 2016 Microstructure of superconducting cable components *Int. J. GEOMATE* Vol 10 p 1906-11
[11] Karpov Y A 2015 Methods of sampling and sample preparation *(Electronic Materials, manual 3rd ed.)* Laboratory of Knowledge p 246
[12] Becker M and Klemm H 1988 Methods of metallographic etching Handbook *M. Metallurgy*