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Investigation of electro-physical and physical-mechanical properties of HTS 2G tapes

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Abstract

High temperature superconducting tapes of 2nd generation (HTS 2G) are being manufactured by several companies worldwide, which use different methods of fabrication of superconducting layers that affect the behaviour of HTS 2G tapes in actual practice. This paper presents the results of the study of HTS 2G tapes delamination process, the influence of alternating temperature impacts on critical current and the behaviour of current carrying capacity of HTS 2G tapes in external magnetic fields. The abovementioned problems can arise in almost any case of designing devices based on HTS 2G tapes. Furthermore, the developed measuring techniques are very important for controlling of output parameters of HTS 2G tapes that are to be manufactured in NRC "Kurchatov institute".

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Keywords: superconductivity; HTS 2G;YBCO; delamination; anisotropy; bending strain; temperature impact

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1. Introduction

One of the most likely ways of beneficial use of 2nd -generation High Temperature Superconductors (HTS 2G) is to employ them in modern "green" electrical equipment (motors, generators, transformers, cables etc.).

Our activity is devoted to developing of techniques for HTS 2G characteristics testing, such as current-carrying capacity in magnetic field with various orientations, tolerance to alternating temperature impact during bending strain, behavior under transverse stresses. All these data might be useful to improve properties of the tapes by means of adjusting of different modes at each stage of their manufacturing process.

We have designed specific experimental technique in order to study the durability of HTS 2G tapes at alternating temperature during bending strain. Bending strain in the tapes Shin et al. (2006), Van der Laan and Ekin (2008) usually appears during the operation in any magnetic systems (coils). Furthermore, additional stress appears during temperature changes, due to the difference in thermal expansion coefficients of the materials in multi-layered tapes.

Another facility we have designed is the delaminating testing machine which allows studying the tapes under transverse stresses. Transverse stress Sakai et al. (2011), Majkic et al. (2013) appears in the HTS tapes during magnetic coil loading because of radial forces, which leads to degradation of superconductive properties of the current-carrying element.

All the properties of the HTS 2G conductors under consideration are important technical characteristics, which should be taken into account for further development of the HTS industry.

2. Experiments

2.1. Samples

The HTS 2G tapes used in this study were produced by SuperPower Inc. Ref. SuperPower and SuperOx Company Lee et al. (2014). The width of these HTS 2G tapes was 4 and 12 mm. Nominal thickness of substrates was 50 µm for SuperOx and 100 µm for SuperPower tapes. The length of experimental samples was changed from 5 to 20 cm.

2.2. Technique for studying of external magnetic field influence on anisotropic current-carrying capacity

It is known Blatter et al. (1994), that external magnetic field applied perpendicularly to superconductive layers has a huge impact on current-carrying capacity of HTS tapes. We have designed an insert for measuring of anisotropy ratio of HTS 2G tapes in an external magnetic field. The experimental diagram is presented in Fig. 1 (a).

The samples were soldered to HTS current leads and fixed to the sample holder for stability. The standard 4-contacts method was used to measure voltage-current characteristics (VCC). The critical current was measured by 1 µV/cm criterion. An external copper magnet was used to generate a DC magnetic field up to 1.4 T. The critical current was measured in the applied external magnetic field, then the cryogenic insert was rotated by a different angle, and measurements were taken again. The installation was designed for angel-resolved measurements in maximum Lorentz force configuration. The angle between the transport current direction and the orientation of the external magnetic field was always 90 degrees. The data of the study of the influence of magnetic field orientation on current-carrying capacity is important for estimating anisotropy of HTS tapes.

2.3. Technique for testing HTS-2G tapes at alternating temperature impact and bending strain

The method to test the stability of superconductive characteristics of the tape at alternating temperature and mechanical strain is based on exposing of the bended piece of the tape to changing temperature.

Initially the sample was mounted on the straight holder to measure the initial value of the critical current of the sample by the 4-contact method. After this measurement, the sample was mounted on the holder with a certain diameter and afterwards the measurement of critical current was repeated.

The next stage of the experiment was to expose the bended sample to alternating temperature. The sample was immersed to liquid nitrogen, and then it was heated to room temperature (RT). Temperature changes from 77 K to approximately 290 K (RT) were repeated 20-40 times, and then critical current was measured again. The aim of this experiment was to define the point, at which the critical current of the sample started to decrease.

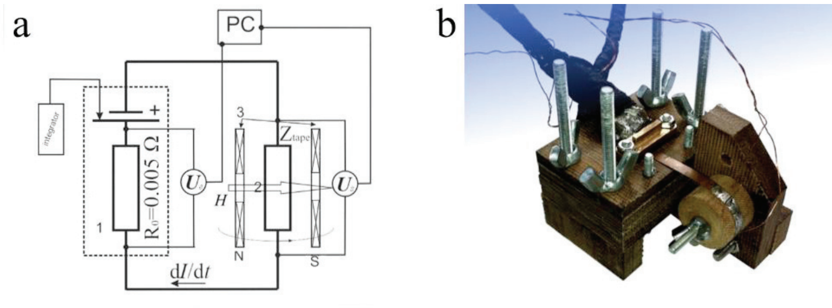

Fig. 1. (a) scheme of angle-resolved device for measuring of HTS critical current in external magnetic field: 1 – integrator, 2 – superconductive sample, 3 – copper magnet poles; (b) the sample of 4 mm tape mounted on the bending holder with a diameter of 20 mm.

In the next experiments we are going to use a developed automatic machine to increase the number of cycles and to cut time expenditure. The device would allow us to expose the sample of HTS 2G tape to larger quantity of thermal cycles. The cooling and heating process will be controlled by the step motor and controller board.

2.4. Studying the HTS 2G tapes under transverse strain

The specific experimental device has been designed to study the delamination phenomena of HTS 2G tapes. It was designed to explore the critical current degradation under transverse mechanical loading and to define the critical value of this loading, which leads to delamination of the sample. The experiment could be conducted both at RT and in liquid nitrogen temperature. The experimental device consisted of the loading machine and the bath for liquid nitrogen.

During the experiment the samples of HTS 2G tapes were soldered between two copper anvils after chemical cleaning. The temperature of soldering was 190ºC. The lower anvil was cylinder-shaped and had a diameter of 17 mm. The upper anvil had a square contact surface of 4x4 mm. After soldering the anvils, the samples were installed in the loading machine. Then the upper anvil was loaded to the point of destroying (delaminating) the sample.

3. Experimental results

3.1. Studying of the critical current anisotropy in external magnetic fields

The experiments were carried out in accordance with the suggested method. The samples were fabricated from commercial HTS 2G tapes from SuperPower Inc. and SuperOx. The overall dimensions were 4 mm wide and 90 mm long. Critical current measurements were done at liquid nitrogen temperature (77 K).

Fig. 2 (a) shows that the current-carrying capacity of the SuperPower sample was less sensitive to the influence of the magnetic field perpendicular to sample surface than the SuperOx sample. Thus, the SuperPower sample had a lower anisotropy ratio.

3.2. Studying of the influence of alternating temperature

The tape 12 mm wide and 110 mm long was selected as a sample to investigate the effect of alternating temperature on the previously bended sample of HTS 2G tapes. After the initial measurement of critical current the sample was bended at the diameter of 20 mm and fixed on the holder. Then the sample was exposed to alternating temperature through steps of 5 cycles. The thermal cycle included cooling to 77 K (by immersion to liquid nitrogen) and heating up to RT with the help of a heater. Fig. 2 (b) shows VCC for the initial bended sample and for the same sample after 180 thermal cycles.

The VCCs in Fig. 2(b) show that 180 thermal cycles didn't affect the critical current of the sample. The critical current was equal to 280±1 A. Consequently it is important to improve the approach to conducting the experiment and to develop an automatic testing machine.

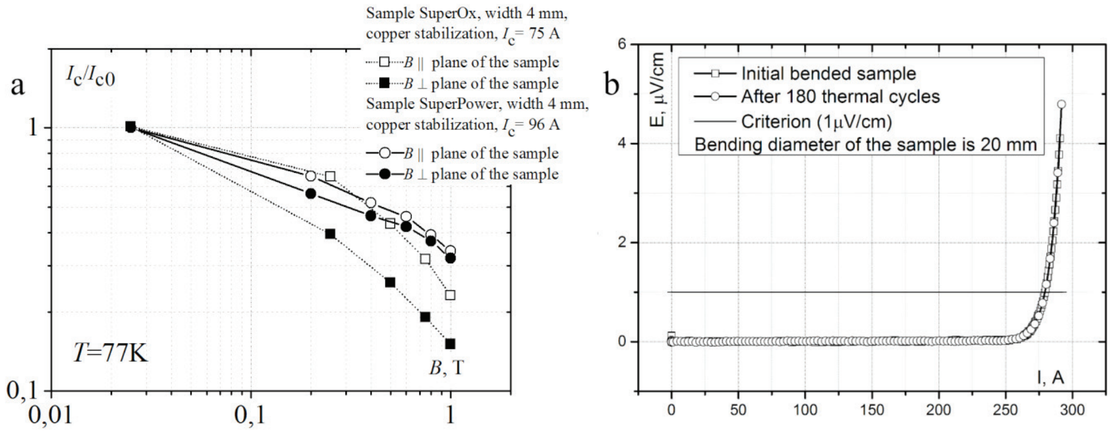

Fig. 2. (a) critical current vs field plot of Superpower/SuperOx 4 mm sample at 77K; (b) voltage-current characteristics of the initial bended sample and exposed to 180 thermal cycles.

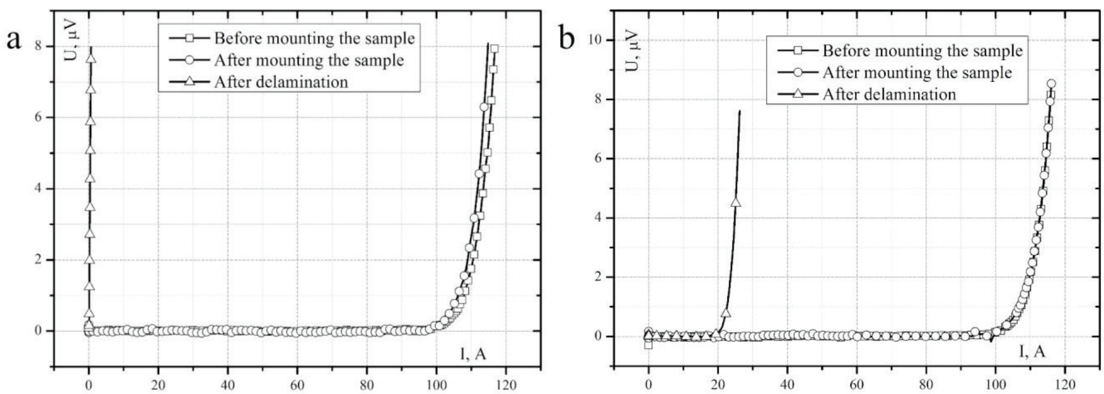

Fig.3. Statistics of critical stress measurements results.

3.3. Delamination experiment

During the delamination experiment the sample of HTS 2G tapes was exposed to critical transverse mechanical strain. This research was conducted at the most important temperatures – RT and liquid nitrogen temperature (77 K) (Fig.3). The average values of critical transverse stress were 7 MPa at RT and 11 MPa at 77 K. Note that the samples had greater critical strengths at 77 K than at RT.

We made an assumption about the mechanisms of layers destruction of the tape when using microstructural analysis. Delamination process began in the HTS layer close to the HTS/silver interface. The further behavior of the crack depended on the defects in HTS ceramics. To confirm this assumption we investigated the critical current degradation under transverse strain.

Fig. 4 (a) shows that in some experiments the sample completely lost its superconductive properties after delamination. On the other hand, Fig. 4 (b) shows that the sample still had some critical current even after delamination. It means that there was some undestroyed superconductive layer, probably, on the buffer layer. The obtained data confirms our hypothesis about the delamination mechanism of HTS 2G tapes.

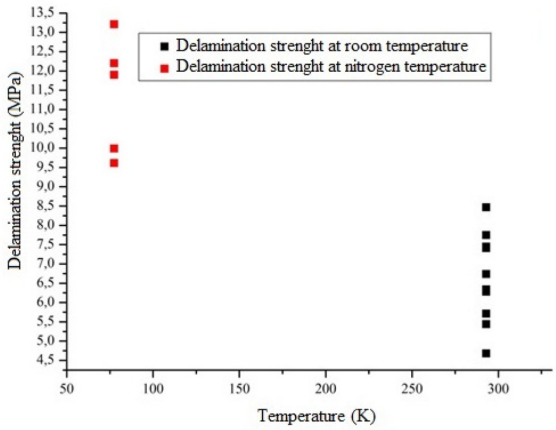

Fig.4. voltage-current characteristics for initial and delaminated samples (a – event 1; b – event 2).

4. Conclusion

This work presents specific experimental facilities for a comprehensive study of primary electro-physical and physical-mechanical properties of HTS 2G tapes.

In order to explore anisotropy of the current-carrying capacity of HTS tapes in external magnetic fields, we developed a low-temperature insert. The insert implements the standard 4-contacts method for VCC registration. As a result of the investigation we have determined that HTS 2G tapes fabricated by SuperOx have greater anisotropy factor of superconductive properties than those manufactured by SuperPower Inc.

We studied the influence of alternating temperature on the critical current of HTS 2G tapes. For this purpose a set of holders was developed, which allowed fixing the sample in a bended position. We found that 180 thermal cycles didn't lead to critical current degradation. Therefore it is necessary to increase the number of thermal cycles. The automatic testing machine for the study of the susceptibility of HTS 2G tapes to alternating temperature impacts has been developed and is under testing now.

We developed an experimental facility to study the influence of transverse tensile strain on HTS 2G tapes. We obtained the values of critical transverse tensile stress that could lead to destruction of HTS 2G tape. They are 7 MPa and 11 MPa at RT and in boiling liquid nitrogen (77K), correspondingly. This brings us to the estimation of acceptable mechanic loads in practical systems. Note that even completely delaminated HTS 2G tapes often had non-zero critical current. That was evidence of the existence of an undamaged superconducting layer on the buffer stack.

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