Archives of Materials Science and Engineering

Volume 69
Issue 1
September 2014
Pages 25-31

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Thermal analysis of SF12050 high temperature superconducting tape

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Received 14.06.2014; published in revised form 01.09.2014

ABSTRACT

Purpose: The paper deals with the determination of the impact and the possibility of heat treatment in order to improve the properties of $YBa_2Cu_3O_{7-x}$ - YBCO 2G HTS high-temperature superconducting tapes.

Design/methodology/approach: Test samples of SF12050 superconducting tape, subjected to heat treatment - annealing in the temperature range of 450-1000°C. Two types of cooling were used on the air and with the furnace. Thus prepared samples were subjected to differential scanning calorimeter DSC - TG NETZSCH STA 409C.

Results: The analysis was also subjected to the influence of temperature on the consistency of the protective layer with the other components of the tape, and a mechanism for destruction of the tape as a result of the impact of elevated temperatures. The paper also contains images of selected sections of the SF12050 superconducting tape which were preheated in the temperature range of 450-1000°C.

Originality/value: Research carried out in the context of the article, made it possible to trace the influence of temperature on the destruction of superconducting tapes. Those studies show the destructive effects that may occur when using the type of tape, in particular as regards their application in the form of windings in transformers. Detailed knowledge of the thermal degradation mechanism of superconducting tapes, may lead to a response on how to modify them in order to avoid the devastating effect of temperature during operation.

Keywords: High-temperature superconductors HTS; DSC; Heat treatment

Reference to this paper should be given in the following way:

J. Jędryka, M. Szota, M. Nabiałek, K. Szota, A. Łukaszewicz, Thermal analysis of SF12050 high temperature superconducting tape, Archives of Materials Science and Engineering 69/1 (2014) 25-31.

PROPERTIES

1. Introduction

Although the high-temperature superconducting materials work at liquid nitrogen temperature, they exhibit properties that allow in a small cross-sectional area for flow of the enormous power densities up to 10^8 A/cm^2 [1-4].

Local discontinuities structure or damage during production have a significant impact on the value of that parameter. The quality of the connections between the different components of the tape is also very important.

The local increase in temperature and an inability to quick heat dissipation causes the deterioration or loss of superconducting properties in areas where Tc (critical temperature) exceeds. It is necessary to choose proper protective materials such as glues or solders. As the superconducting materials are mostly ceramics, its thermal conductivity is very low and equals approximately 15 W/mK and additionally several times greater in the a-b plane than in a direction perpendicular thereto [5-10].

Another very important parameter for high temperature superconductors is the coefficient of thermal expansion. The coefficient of thermal expansion for YBCO superconductor in the a-b plane is $7*10^{-6}K^{-1}$ for temperatures higher than Tc and $3.4*10^{-6}K^{-1}$ for temperatures higher than Tc. The thermal expansion in the c-axis direction is $12*10^{-6}K^{-1}$ for temperatures higher than Tc, and $8.2*10^{-6}K^{-1}$ for temperatures lower than Tc [5-7, 11-14].

With the above-mentioned protective treatments, and designed to connect the elements by gluing, soldering and brazing, it is possible to significantly enlarge the thermal conductivity of the entire system.

2. Methodology and material

For studies high-temperature superconducting tape of the second generation HTS (Second Generation High Temperature Superconductors) of SF 12050 series (the initials SF mean stabilized free – superconducting phase is not stabilized by another phase, and 12050 is the width of 12 mm the thickness of 0.055 mm) were used. Chemical composition of SF12050 tape was presented in Table 1.

Table 1.
Chemical composition of HTS 2G SF12050 [8]

Chemical composition, wt%											
Co	Cr	Cu	Fe	Mn	Mo	Ni	Si	Ag	W	V	*
2.3	15	0.5	5	1	15	52	0.1	6.3	4	0.3	2

*REBCO; RE – rare earth elements: Eu, Dy, Gd, Y, Sm; BCO means: Ba, Cu, O

- critical current IC at liquid nitrogen temperature (77 K, in a single field) minimum value 240 A±10%,
- width 12 mm,
- thickness 0.055 mm,
- thickness of silver layer 2 μm ± 0.5 μm,
- the substrate is an alloy Ni and Mo and alloying elements of the trade name Hastelloy C-276,
- magnetic properties of the substrate – non-magnetic,
- resistivity substrate 125 μΩcm.

Figure 1 shows a roll of SF12050 superconducting tape, length 10 m.

Fig. 1. Scroll of superconducting tapes of SF12050 series

A superconducting tape is wrapped around on specially spool which protects tape against mechanical damage and environmental influence.

3. Results

The aim of the study was to determine the temperature changes occurring during annealing of SF12050 high-temperature superconducting tapes. The results of the study were used to create heat treatment plan with the aim of modifying the properties and structure of the SF12050 tape. The tests were performed using a differential scanning calorimeter DSC-TG NETZSCH STA 409C, which is shown in Fig. 2. The interior of the heating chamber is presented in Fig. 3 [15].

The above-mentioned test equipment allows to determine the thermal effects occurring during the heating of the material.

The result is a curve showing the occurrence of exothermic transformation (with heat devotion to the system), and endothermic (heat taking from the system).

The heating rate was 10 K/min and 20 K/min. The test was performed under an atmosphere of argon, which flow through the system was 100 ml/min. The sample was cut into small pieces and placed in a corundum crucible (Al_2O_3) 5 mm in a diameter. As a reference sample empty corundum crucible was used. A thermocouple was placed on the underside of the sample. Figs. 4 and 5 presented DSC curves obtained by heating SF12050 the superconducting tape.

Fig. 2. Differential Scanning Calorimeter NETZSCH STA 409C

Fig. 3. The interior chamber of the differential scanning calorimeter NETZSCH STA 409C

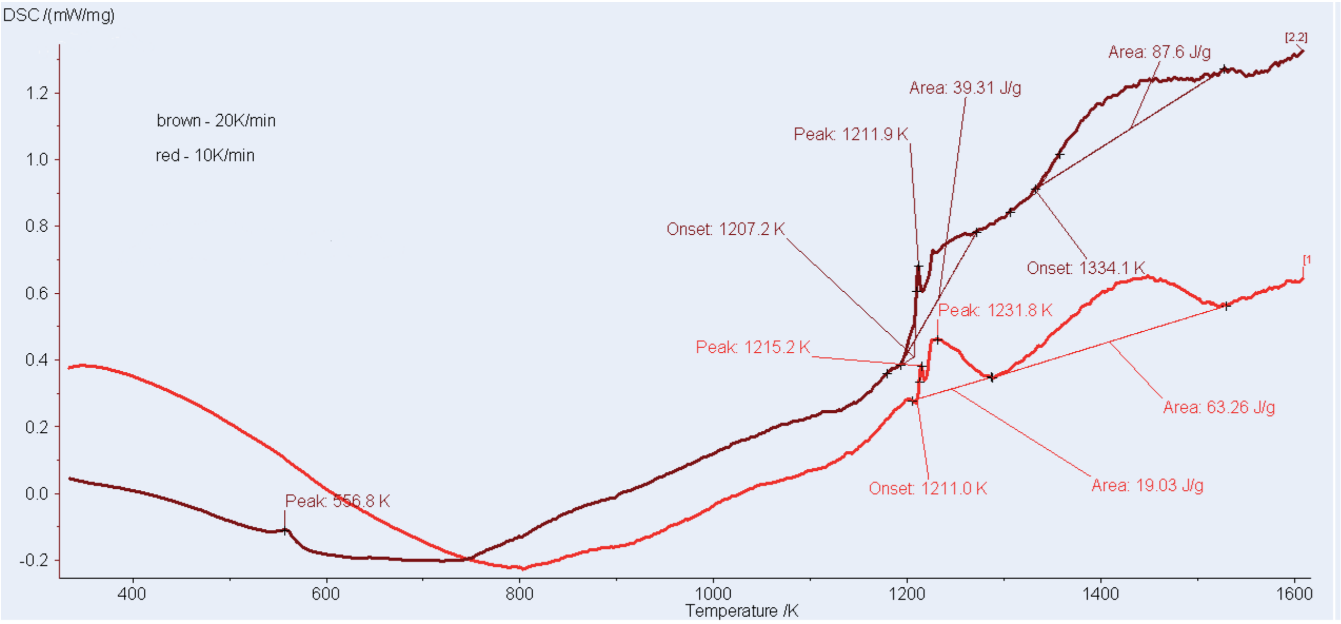

Fig. 4. Segments of DSC curves in the temperature range 300 K-1600 K obtained by heating tape SF12050

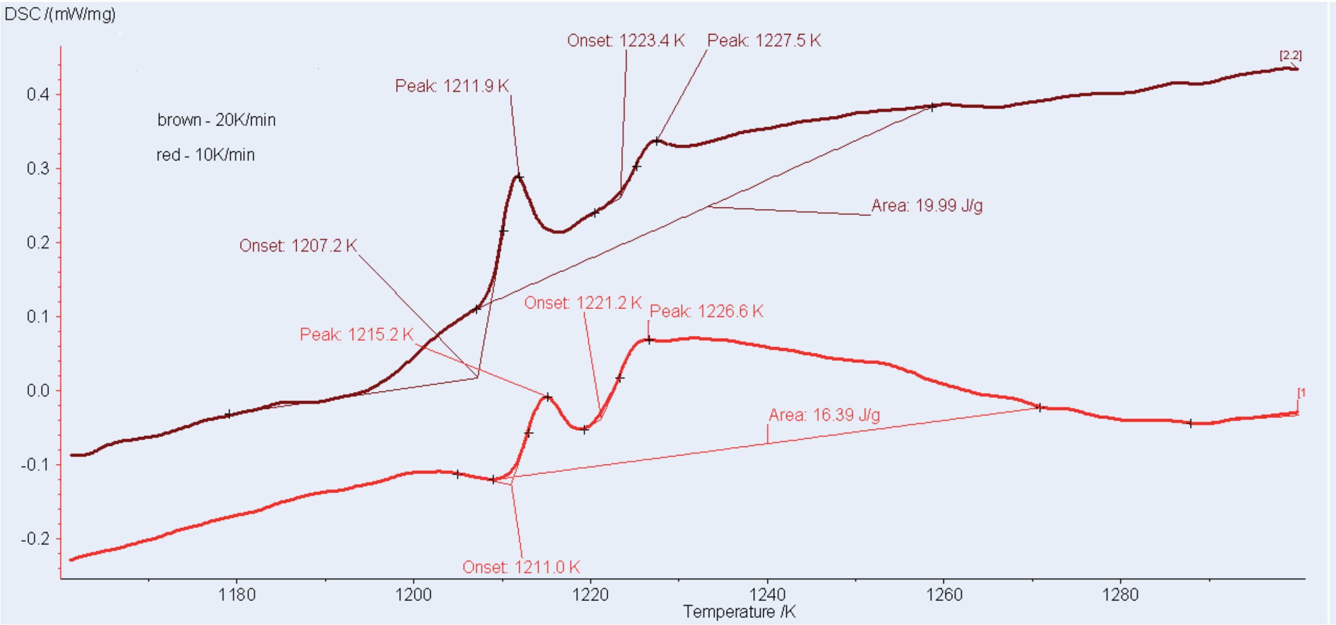

Fig. 5. Clipping the DSC curve in the temperature range 1160 K-1300 K obtained by heating SF12050 tape

In Fig. 4 segments of DSC curves in the temperature range 1600 K-300 K obtained by heating SF12050 tape are presented. There are two curves: brown, arising from heating at a rate of 20 K/min and red tape plotted for SF12050 preheated at 10 K/min in the graph. The changes taking place during warm-up run with devotion heat to the environment, which is exothermic reactions occur. Some interesting points in those temperatures, where there are peaks showing the occurrence of phase transitions may be noted. At a temperature of 556.8 K the polymer layer form surface was melted, and about 800 K degradation process of the tape from the substrate side was started. The temperature range between 1160 K-1300 K is really interesting. A segment of DSC curves in the temperature range is presented in Fig. 5.

The section curve in the temperature range of 1195 K-1205 K – relates to a change of heat of a proper system. The peaks seen in the temperature range of 1200 K-1270 K are related to melting silver, which has been applied as a protective coating of the SF12050 tape. The heat capacity of the system in the above-mentioned temperature range amounts to, for the curve brown – 19.99 J/g and the red curve – 16.39 J/g.

Knowing the temperature ranges in which the phase transitions occur for the tape SF12050 tape, a rotatable plan of heat treatment is proposed. Annealing temperature of superconducting tapes was to check the resistance to high temperatures that can occur during the flow of current through a superconductor, and the ability to modify the heat and its impact on the properties and structure of the SF12050 superconducting tape. The local increase in temperature, of a superconducting tape section, causes a damage to the protective coating of superconducting tape and the superconductor layer itself.

For each combination of temperature and time of heat treatment SF12050 superconducting tape sections 40 mm length were prepared. Then, superconducting tape were annealed in the atmosphere of the furnace. In Figs. 6-13 selected sections of SF12050 high-temperature superconducting tapes are preheated at temperatures of 200°C-700°C, during time of 2 h-100 h. Also the temperature going beyond a rotatable plan, up to 1000°C was taken into account. In Figs. 14-19 selected sections of the superconducting SF12050 tapes preheated at temperatures 720°C-1000°C during time 2 h-48 h were presented. After annealing, the samples were cooled in air. The sample annealed at 1000°C during time of 2 h was cooled down with the furnace.

Fig. 6. Fragment of SF12050 superconducting tape, subjected to annealing at 450°C during time of 48 h, view from the side of the silver layer, air cooling

Fig. 7. Fragment of SF12050 superconducting tape, subjected to annealing at 500°C during time of 6 h, view from the side of the silver layer, air cooling

Fig. 8. Fragment of SF12050 superconducting tape, subjected to annealing at 550°C during time of 48 h, view from the side of the silver layer, air cooling

Fig. 9. Fragment of SF12050 superconducting tape, subjected to annealing at 550°C during time of 48 h, view from the side of the substrate, air cooling

Fig. 10. Fragment of SF12050 superconducting tape, subjected to annealing at 600°C during time of 2 h, view from the side of the silver layer, air cooling

Fig. 11. Fragment of SF12050 superconducting tape, subjected to annealing at 650°C during time of 48 h, view from the side of the substrate, air cooling

Fig. 12. Fragment of SF12050 superconducting tape, subjected to annealing at 700°C during time of 6 h, view from the side of the silver layer, air cooling

Fig. 13. Fragment of SF12050 superconducting tape, subjected to annealing at 700°C during time of 6 h, view from the side of the substrate, air cooling

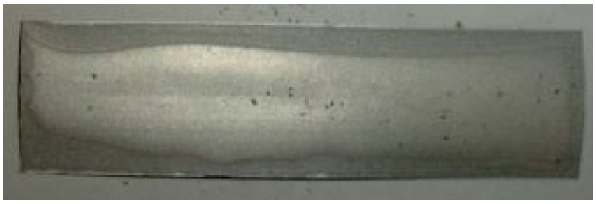

Fig. 14. Fragment of SF12050 superconducting tape, subjected to annealing at 720°C during time of 48 h, view from the side of the silver layer, air cooling

Fig. 15. Fragment of SF12050 superconducting tape, subjected to annealing at 720°C during time of 48 h, view from the side of the substrate, air cooling

From the above Figs. it is indicated that at temperatures above 500°C the degradation of superconducting tape visible to the naked eye occurs. Discoloration on the silver coating occurs due to influence of temperature. At a temperature of 700°C the bulge appears on the tape surface, and the color of the substrate is changed to black. The bulge on the surface is visible at the edges of the tape.

The increase of the temperature to 720°C results in bulging of the silver layer over the entire length of the machined tape. At that temperature there is also blown from the substrate. As a result of the annealing at 800°C the tape bends in an arc. Bending was created during a 2-hour annealing. After annealing at 800°C for six hours there was almost complete degradation of the silver coating and the substrate. A silver layer can be seen only at the edge of the tape. Annealing at 1000°C results in the total destruction of the tape.

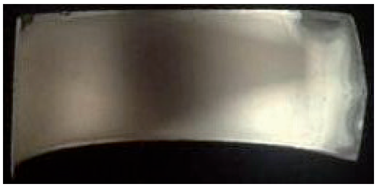

Fig. 16. Fragment of SF12050 superconducting tape, subjected to annealing at 800°C during time of 2 h, view from the side of the silver layer, air cooling

Fig. 17. Fragment of SF12050 superconducting tape, subjected to annealing at 800°C during time of 6 h, view from the side of the silver layer, air cooling

Fig. 18. Fragment of SF12050 superconducting tape, subjected to annealing at 800°C during time of 6 h, view from the side of the substrate, air cooling

Fig. 19. Fragment of SF12050 superconducting tape, subjected to annealing at 1000°C during time of 2 h, cooling with furnace

4. Conclusions

1. From the DSC curves show that at a temperature of 556.8 K the polymer layer applied to the surface is melted and the process of degradation of superconducting tape from the substrate starts at about 800 K.
2. The peaks seen in the temperature range of 1200 K-1270 K are related to melting of silver, which has been applied as a protective coating SF12050 tape.
3. Outcarried heat treatment indicate that it is possible to use it in order to modify the SF12050 superconducting tape, at temperatures up to about 500°C. The plastic layer is burnt but destructions are not visible to the naked eye on the tape surface. Above that temperature, degradation occurs mainly to the substrate. At a temperature of 700°C bulging appears on the strip surface, and the color of the substrate is changed to black. At a temperature of 720°C, bulging of the silver layer over the entire length of the measuring section and the substrate burnout follows. As a result of the annealing at 800°C the tape bends in an arc, almost completely degrading the silver coating and the substrate. Annealing at 1000°C results in the total destruction of the tape.

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