pISSN 1229-3008 eISSN 2287-6251
Progress in Superconductivity and Cryogenics
Vol.19, No.2, (2017), pp.25~28 https://doi.org/10.9714/psac.2017.19.2.025

Enhancement of delamination strength in Cu-stabilized coated conductor tapes through additional treatments under transverse tension at room temperature

Hyung-Seop Shin[a,*], Zhierwinjay Bautista[a], Seung-Hyun Moon[b], Jae-Hun Lee[b], and Byoung-Jean Mean[b]

[a] *Andong National University, Andong, Kyungbuk 35729 Korea*
[b] *SuNAM Co Ltd., Anseong, Gyunggi-do, 17554 Korea*

(Received 2 June 2017; revised or reviewed 15 June 2017; accepted 16 June 2017)

Abstract

In superconducting coil applications particularly in wet wound coils, coated conductor (CC) tapes are subjected to different type of stresses that could affect its electromechanical transport property. These include hoop stress acting along the length of the CC tape and the Lorentz force acting perpendicular to the CC tape's surface. Since the latter is commonly associated with the delamination problem of multi-layered REBCO CC tapes, more understanding and attention on the delamination phenomena induced in the case of coil applications are needed. Difference on the coefficient of thermal expansion (CTE) of each constituent layer of the CC tape, the bobbin, and the impregnating materials is the main causes of delamination in CC tapes when subjected to thermal and mechanical cycling. In the design of degradation-free superconducting coils, therefore, characterization of the delamination behaviors including mechanism and strength in the multi-layered REBCO CC tapes becomes a critical issue. Various trials to increase the delamination strength by improving interface characteristics at interlayers have been performed. In this study, in order to investigate the influences of laser cleaning and Ag annealing treated at the substrate side surface, transverse tensile tests were conducted under different sample configurations using 4.5mm x 8 mm upper anvil. The mechanical delamination strength of differently processed CC samples was examined at room temperature (RT). As a result, the Sample 1 with the additional laser cleaning and Ag annealing processes and the Sample 2 with additional Ag annealing process only showed higher mechanical delamination strength as compared to the Sample 3 without such additional treatments. Sample 3 showed quite different behavior when the loading direction is to the substrate side where the delamination strength much lower as compared to other cases.

Keywords: REBCO CC, Delamination strength, Laser cleaning, Ag annealing, Transverse tension, Test configuration

1. INTRODUCTION

High temperature superconducting (HTS) 2G coated conductor (CC) tapes have been made remarkably technical advance and achieved greatest potentials due to its high critical current density (J_c), and superior mechanical and electromechanical properties for large scale applications [1, 2]. However, when they are adopted in such applications, HTS tapes might experience deformation acting on different direction and various mechanical stresses such as hoop stress. This stress will act on the surface of the CC tapes in transverse directions and the stress /strain induced by mismatch of the coefficient of thermal expansion (CTE) among each constituent materials present on the CC tape causes the I_c to degrade through the occurrence of delamination [3]. Furthermore, in some superconducting device applications, repeated loading due to rotational stresses and thermal cycling (repetitive cool down and removal from cryogen temperature) might worsen the delamination induced [4]. As reported elsewhere, the I_c of an epoxy impregnated double pancake coil degraded due to at almost 5 thermal cycles [3].

In order to improve the structure and capabilities of the CC tapes in regards with this delamination issues, many research groups have been conducting delamination tests with their preferred methods (*i.e.* anvil, pin-pull, cleavage, and peel test methods) including the transverse compressive loading [5-10]. In addition, the peel test, which might be some relationship with the delamination occurred in the multi-layered CC tapes, could be carried out at various peeling angles (from 90° to 180°) and the peel strength of a CC tape was defined as the steady-state peeling load determined from a load–displacement curve [11]. A four-point bending test was also used in order to determine the interfacial cohesive energy of the CC tapes [12]. Therefore, the HTS tapes nowadays have been mechanically supported by copper (Cu) materials layered either by electroplating or by solder laminating for stabilization during operation and quenching conditions. Also, further mechanical reinforcement can be achieved by brass foil lamination after Cu-stabilizing [13, 14]. In the report of Shin et al. [15], the impurities in the substrate part may cause the CC tape to lower delamination strength. The characterization of delamination behavior to CC tapes in transverse loading is essentially needed for the fabrication of delamination-free superconducting coil. Therefore, the effect of transversely applied loading to the CC tapes

* Corresponding author: hsshin@anu.ac.kr

should also be considered for the coil fabrication. In our previous reports, a transverse tensile testing frame was devised to conduct a systematic delamination testing procedure [6, 15].

Up to now, most of the delamination researches have been focused on improving the delamination strength mainly on the superconducting layer side, but it is also necessary to pay attention on the delamination issue which may occur on the substrate layer side of the CC tapes.

In this study, therefore, the delamination characteristics at the substrate layer side of three differently processed GdBa2Cu3Oy (GdBCO) CC tape samples were investigated at room temperature (RT) under different transverse loading configurations using the anvil test method. The effectiveness of both laser cleaning and Ag-annealing treatment done on the substrate layer side to improve the delamination strength of CC tapes was examined.

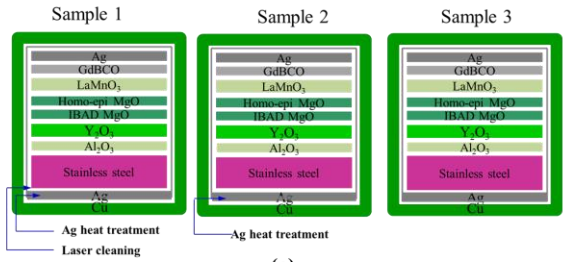
2. EXPERIMENTAL PROCEDURES

2.1. Samples

The CC tape samples supplied are fabricated by reactive co-evaporation by deposition and reaction (RCE-DR) process. The samples are classified into three differently processed CC tapes depending on the adoption of laser cleaning and Ag annealing treatment, as shown in Fig. 1(a). All of the samples have same configurations where GdBCO superconducting film was deposited on the stainless steel substrate by IBAD/RCE-DR process. The buffer layers served as a diffuson barier during the deposition of superconducting film. The Ag cap layer was sputtered onto the superconducting film as protection layer. On the other hand, additional processes of laser cleaning and Ag-annealing were performed at the substrate layer side of CC tapes, and they can be classified as follows; Sample 1 which undergoes a laser cleaning at the back surface of the substrate before it was slit from a 12mm to the desired width and conducting a Ag heat treatment after the substrate side was sputtered. Sample 2 was only processed by Ag heat treatment without the laser cleaning. Sample 3 was conventionally prepared with no laser cleaning and no Ag heat treatment at the substrate side. Then copper layer was electroplated surrounding the whole CC tape for both thermal and mechanical stability.

2.2. Transverse tension test

In the sample preparation for delamination testing, a soldering technique was used to attach the CC tape to the upper and lower Cu anvils. A flux ($ZnCl_2$) was applied for easy soldering and in order to equally distribute the In-Bi solder material on the effective contact area of the CC sample to both anvils. A 4.5 mm x 8 mm upper anvil size was used in the transverse tension test. This dimension of upper anvil used covers the whole CC tape's width representing its actual condition when impregnated in the case of superconducting coil applications. A sample holder was utilized to ensure complete alignment among both anvils and CC tape sample during the soldering process for



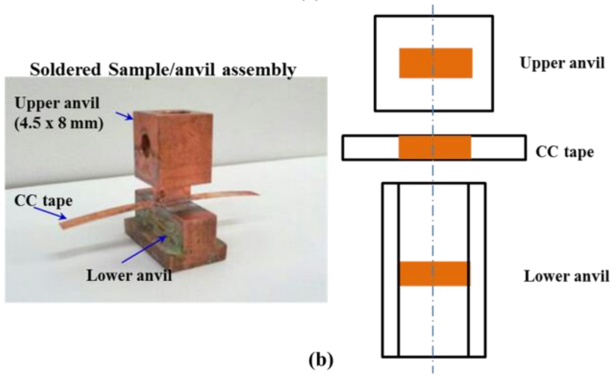


Fig. 1. (a) Sample configurations of three differently processed CC tapes and (b) Appearance of soldered upper anvil/CC tape/lower anvil assembly.

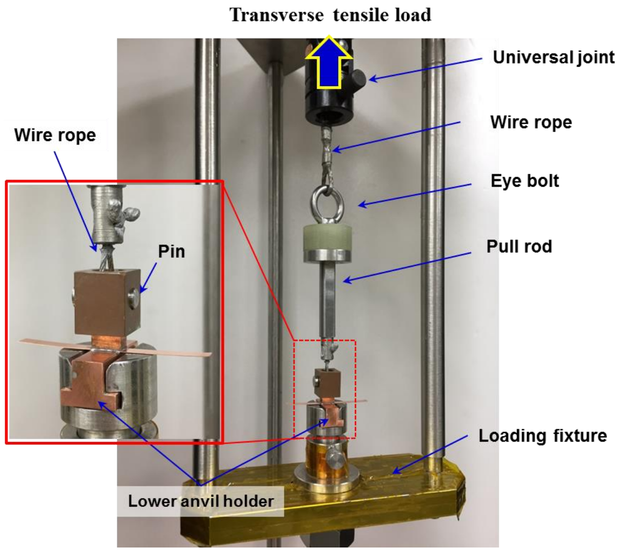


Fig. 2. Setup for mechanical delamination under transverse tensile loading at RT.

sample mounting. Pressure was applied uniformly on the contact (soldered) area by applying a dead-weight which also enhances the adhesion of CC sample to both anvils. Soldering was done at ~120℃ and sample mounting preparation was similarly conducted which was reported elsewhere [15]. Fig. 1(b) shows an appearance of the soldered sample/anvil assembly with 50 mm length CC tape where the shaded rectangles corresponded to the contact area of CC tape to both anvils. During sample mounting, two different assembly configurations were prepared; one is the superconducting layer of the CC tape directed to the upper anvil (which corresponded to the load direction) and the other is in opposite position.

After soldering, the attached sample/anvil assembly was mounted on a delamination testing apparatus, as shown in Fig. 2. For tensile load-line alignment, it is composed of a universal joint, wire rope, eye bolt, pull-rod, the sample/anvil assembly, and the loading fixture. The transverse tensile test was performed at RT and at a crosshead speed (ram rate) of 0.5 mm/min. The delamination strength was derived using the peak load obtained through the delamination tests, where the peak load was divided by the contact area of 32 mm^2 (4 x 8 mm) which is corresponding to the upper anvil length times the width of sample used [6, 15].

3. RESULTS AND DISCUSSION

Fig. 3 shows the delamination strength measured in three differently processed GdBCO CC samples. In the figure, the closed symbols indicate the case that the superconducting layer side positioned toward the upper anvil, and the open symbols indicate the opposite case that the substrate layer to the upper anvil one. The delamination strength was derived from the peak load obtained through the transverse tensile test at RT. For each sample, 5 tests per each configuration were conducted. The closed symbol indicates that the superconducting layer side was on the upper anvil side and the open one means the substrate layer directed to the upper anvil side. There existed some scattering of the delamination strength even though the variation was different in three samples adopted. In the figure, it showed that the sample configuration did not so much affected the delamination strength of CC tapes. The average delamination strength of 10 tests for Sample 1, Sample 2 and Sample 3 measured at RT was 32.2 MPa, 32.7 MPa, and 22.8 MPa, respectively. Both Sample 1 and Sample 2 which were treated by Ag annealing and/or laser cleaning showed some increase in mechanical delamination strength as compared to the cases of Sample 3 without any treatment.

Since Sample 1 and Sample 2 showed almost similar mechanical delamination strength, as a result, it can be said that the laser cleaning added to the substrate surface looks effective in removing macro-size particles such as impurities existed on the substrate surface consequently improving the uniformity and could be suppress the ballooning phenomena occurs during repeated cool-down of CC tapes, while the Ag heat treatment might contribute to improve the interfacial strength among layers resulting in the enhancement of delamination strength.

Most of the failure occurred at the superconductor layer side, but some cases initiated on the substrate layer side of CC tapes where the substrate layer was directed to the upper anvil side of loading direction. On the other hand, in Sample 3 which is the conventional CC tapes, especially, the substrate layer side ones exhibited lower delamination strength among three samples tested, but it was still comparable values from the previous results [15]. Considering these results, if the delamination tests are performed at cryogenic temperatures, some enhancement of the delamination strength will be expected.

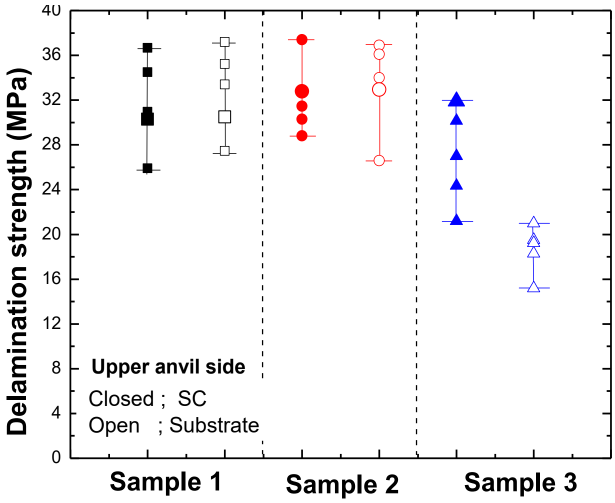


Fig. 3. Mechanical delamination strength of CC tape samples.

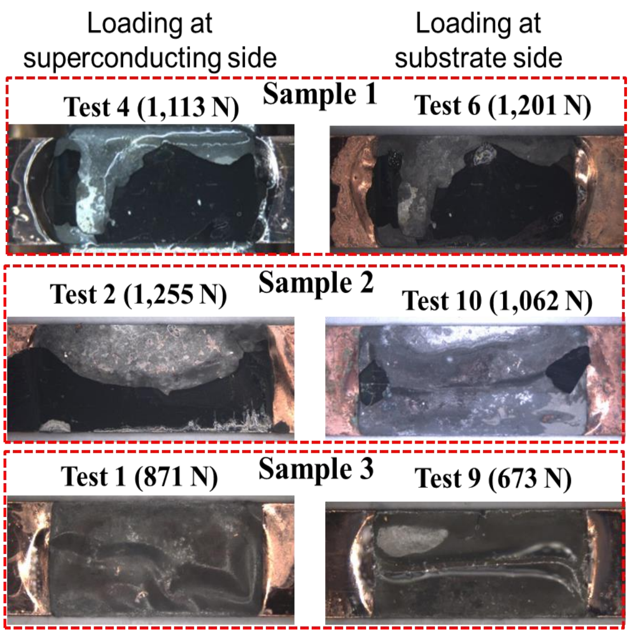


Fig. 4. Failure morphologies of differently processed CC tapes under transverse tension according to sample configurations.

The morphologies of the failure occurred in CC tapes under the transverse tensile loading according to loading configurations are shown in Fig. 4. No distinct difference in failure morphologies according to sample configurations existed. Sample 1 and 2 showed mainly the fracture of Cu layer and delamination occurred at the superconducting layer, while Sample 3 showed just bulging of Cu stabilizing layer part, representing a lower peak load at break point which is shown in parentheses, respectively. Further analysis and fractographic observation are needed to clarify whether interfacial characteristics among layers in GdBCO CC tapes are improved through the laser cleaning and Ag heat treatment which were adopted in this study.

4. SUMMARY

The delamination strength of Cu-stabilized GdBCO CC tapes with/without the additional treatment at the substrate layer side was evaluated using an anvil test method by transverse tensile test at RT. The CC tapes showed similar range of mechanical delamination strength regardless of different sample configurations adopted. Sample 3 without any additional treatment showed a different behavior when the loading is applied on the substrate side where the delamination strength was much lower as compared to Sample 1 and 2 cases. This result explains that the additional treatment such as Ag annealing to the substrate layer side of the CC tapes have enhanced the delamination strength at RT.

ACKNOWLEDGMENT

This work was supported by a grant from the Power Generation & Electricity Delivery Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) funded by the ministry of Trade, Industry and Energy (MTIE) (No. 20131010501800). This work was partially supported by a grant from National Research Foundation of Korea (No. 2017-001109) funded by the Ministry of Science, ICT and Future Planning (MSIP), Republic of Korea.

REFERENCES

[1] J. H. Lee, H. Lee, J. W. Lee, S. M. Choi, S. I. Yoo and S. H. Moon, "RCE-DR, a novel process for coated conductor fabrication with high performance," *Supercond. Sci. Technol.*, vol. 27, pp. 044018, 2014.

[2] A. Nisay and H. S. Shin, "Mechanical and electromechanical analysis in differently stabilized GdBCO coated conductor tapes with stainless steel substrate," *Prog. Supercond. Cryo.*, vol. 15 pp. 29-33, 2013.

[3] T. Takematsu, R. Hu, T. Takao, Y. Yanagisawa, H. Nakagome, D. Uglietti, T. Kiyoshi, M. Takahashi and H. Maeda, "Degradation of the performance of a YBCO coated conductor double pancake coil due to epoxy impregnation," *Physica C*, vol. 470, pp. 674-677, 2010.

[4] A. L. Mbaraku and J. Schwartz, " Fatigue behavior of Y-Ba-Cu-O/ hastelloy-C coated conductor at 77 K," *IEEE Trans. Appl., Supercond.*, vol. 18, pp 1743-1752, 2008.

[5] D. C. van der Laan, J. W. Ekin, C. C. Clickner and T. C. Stauffer, "Delamination strength of YBCO coated conductors under transverse tensile stress," *Supercond. Sci. Technol.*, vol. 20, pp. 765-770, 2007.

[6] A. Gorospe, A. Nisay, J. R. Dizon and H. S. Shin, "Delamination behaviour of GdBCO coated conductor tapes under transverse tension," *Physica C*, vol. 494, pp. 163– 167, 2013.

[7] G. Majkic, E. Galstyan, Y. Zhang and V. Selvamanickam, "Investigation of delamination mechanisms in IBAD-MOCVD REBCO coated conductors," *IEEE Trans. Appl. Supercond.*, vol. 23, p. 6600205, 2013.

[8] H. Sato, N. Nakamura, S. Fujita, M. Daibo and Y. Iijima, "Evaluation of transverse tensile stress characteristics of GdBCO Coated Conductors," *Physics Procedia*, vol. 65, pp. 145-148, 2015.

[9] Y. Yanagasiwa, H. Nakagome, T. Takematsu, T. Takao, N. Sato, M. Takahashi and H. Maeda, "Remarkable weakness against cleavage stress for YBCO-coated conductors and its effect on the YBCO coils performance," *Physica C*, vol. 471, pp. 480-485, 2011.

[10] A. Grether, C Scheuerlein, A. Ballarino and L. Bottura, "Electromechanical behavior of REBCO tape lap splices under transverse compressive loading," *Supercond. Sci, Technol*., vol. 29, p. 074004, 2016.

[11] Y. Zhang, et al., "Adhesion strength study of IBAD-MOCVD-based 2G HTS wire using a peel test," *Physica* C. vol. 473, pp. 41-47, 2012.

[12] N. Sakai, S. Lee, N. Chikumoto, T. Izumi and K. Tanabe, "Delamination behavior of Gd123 coated conductor fabricated by PLD," *Physica C*, vol. 471, pp. 1075-1079, 2011.

[13] Z. Bautista, H.S. Shin, B. J. Mean and J. H. Lee, "Effects of differently hardened brass foil laminate on the electromechanical property of externally laminated CC tapes," *Prog. Supercond. Cryo.*, vol. 18, No. 4, pp. 15-20, 2016.

[14] Z. Bautista, H. S. Shin, J. H. Lee, H. Lee and S. H. Moon, "Influence of brass laminate volume fraction on electromechanical properties of externally laminated coated conductor tapes," *Prog. Supercond. Cryo.*, vol. 18, No. 3, pp. 6-9, 2016.

[15] H. S. Shin and A. Gorospe, "Characterization of transverse tensile stress response of critical current and delamination behavior in GdBCO coated conductor tapes by anvil test," *Supercond. Sci. Technol.*, vol. 27, p. 025001, 2014.