Coated Conductors under Tensile Stress

Anca Antonevici ‡§ Alain Villaume †‡ Catherine Villard †§ André Sulpice †§ Pierre Brosse Maron †§ Daniel Bourgault †‡ Laureline Porcar †§
† Consortium de Recherches pour l’Emergence des Technologies Avancées, CNRS, Grenoble, France
§ Centre de Recherches sur les Très Basses Températures, CNRS, Grenoble, France
‡ Laboratoire de Cristallographie, CNRS, Grenoble, France

Résumé.
Critical current dependence versus strain is obtained for in-situ axial stress experiments on ISD YBCO and DyBCO coated conductors. The drop of critical current due to the apparition of first cracks in the superconducting ceramics is related to the passage in the plastic region of the substrate for a strain of about 0.3% and a stress higher then 500MPa. The superconductivity is preserved between the cracks.

1. Introduction
Superconducting films on flexible substrates, or coated conductors (CC), are the base for new HTS devices like coils, transmission cables, motors, etc. The fabrication of such devices induces a mechanical stress in CC which may cause the degradation of the ceramics and implicitly their electrical properties. Understanding their stress tolerance is crucial in order to fix the parameters for mechanical winding and to know the limits of tapes exploitation.

Here we report our investigations of critical current (Ic) under tensile stress for ISD-YBCO and DyBCO CC fabricated at Theva-GmbH, Germany.

2. Experimental
The experimental device is presented in Fig. 1. The sample is horizontally clamped into the jaws, which also play the role of current leads. A strain gauge is glued on the backside of the tape. The sample holder is mounted in series with a transducer between the arms of a pliers. A pushing ball activates the pliers, imposing the strain on the sample. All the tests were performed at 77K in self field. Ic was determined from DC transport measurements with a 1μV/cm electric field criterion.
3. Sample description

We studied 3 types of Re-123 CC fabricated by ISD [1] and thermal evaporation [2],[3] at Theva-GmbH Germany in different runs. The sample specifications are presented in Tab. 1. Magneto-optical imaging of the flux penetration (presented in this conference [4]) for samples YBCO2 and DyBCO1 shows a good homogeneity of the films. YBCO1 presents extended penetration areas corresponding to defects which explain the Ic difference of a factor 1.4 compared to YBCO2.

| sample | Substrate | Buffer layer | ReBCO cross-section | Protective layer | Jc $\text{MA/cm}^2$ |
|--------|-----------|--------------|---------------------|------------------|-----------------|
| YBCO1  | Hastelloy | ISD-MgO      | 600nm x 8mm         | Au-100nm         | 1.2             |
| YBCO2  | C276      | 3 µm         | 600nm x 8mm         | Au-100nm         | 1.66            |
| DyBCO1 | 90 µm     |              | 2 µm x 10mm         | Ag-300nm         | 0.5             |

4. Results and Discussion

In Fig. 2a we show the normalised critical current versus strain for all samples. At low strain, Ic is nearly constant and reversible with the applied stress. YBCO2 shows a slight increase of critical current of 2.2% with applied stress which implies a compressive residual strain of 0.2% [5]. At higher strain, above 0.27-0.3%, Ic drops irreversibly due to the appearance of the first cracks in the film. As we increase or just maintain the strain, the cracks propagate across the tape, sometimes blocked in their way and new cracks are created in more resistant areas nearby, reducing the film section.

The distribution of the cracks is very non-homogenous along the tape, with a higher density close to the jaws where the tape is weakened by the transverse "constrained compression" of the jaws. The strain gauge, glued in the middle of the tape between the voltage pads strengthens the tape locally, and slightly
underestimates the strain (about 2%) . When cracks appear outside the voltage pads, they can induce a superconducting transition that thermally propagates toward the center. In the case of YBCO1, the Ic versus strain curve, located between the values 0.27% and 0.34% of strain corresponds to sharp U(I) thermal transitions sensitive to the speed of the current ramp. If we eliminate the side effects (by an additional tin layer soldered on the tape close to the jaws - the case of DyBCO1), the first cracks formed inside the voltage pads area and the transition is intrinsic, depending only on the reduced film section.

Fig. 2b shows that samples YBCO2 and DyBCO1 have almost the same stress-strain characteristic having a slightly lower Young Modulus (180GPa) - compared to YBCO1 (230GPa) - due to the constant evolution of the elaboration process[6]. YBCO2 and DyBCO1 also have a lower yield limit. For all the samples, the drop to zero of the Ic coincides with the yield limit of the substrate ( 0.34% for YBCO1 and 0.3% for DyBCO1 and YBCO2). Here, the strain increases for an almost constant

**Fig. 2.** (a) Normalised critical current versus strain at 77K for samples YBCO1, YBCO2 and DyBCO1. (b) Stress versus strain for YBCO1 and DyBCO1

**Fig. 3.** (a) Optical image of crack network in YBCO/Au and MgO after etching of the YBCO (applied stress of 800MPa). The cracks (200 nm wide and a mean separation of about about 14 μm) are perpendicular to the direction of applied stress . (b) Magneto-optical image of the cracks at 10K and 50mT applied field
applied stress.

In the plastic region, the ceramic layer becomes a network of cracks and current percolation is not possible any more. Fig. 3.a is an optical image of YBCO1 with a half etched YBCO/Au layers. We notice the presence of cracks in the MgO layer. SEM observations (not presented here) shows that cracks cuts the Re-123 grains and follows the grain boundaries of MgO [5], [7].

Magneto-optical imaging reveals the crack network (Fig. 3.b). The magnetic flux penetrates in the rifts (light green) but is expelled in the superconductor bridges (dark green). The superconducting properties are not destroyed between the cracks.

5. Conclusion

The influence of stress on critical current was studied for 3 kinds of coated conductors (CC), YBCO and DyBCO based. The CC is a composite with a brittle ceramic layer which does not break uniformly. The cracks appear at the weakest points which cross the yield limit of the substrate (about 0.3%), then propagate across and along the tape. Each test system is susceptible to influencing the mechanical behaviour of the tape: in our case the strain gauge locally strengthened the tape while the jaws weakened it. A future study of in-situ magneto-optical imaging under stress will show the link between appearance of cracks and propagation of them to the degree of homogeneity of the sample.

Acknowledgments

The authors are grateful to W. Prusseit from THEVA for his collaboration

References

[1] M.Bauer, R.Metzger, R.Semerad, P.Berberich, H.Kinder, Mat. Res. Soc. Symp. Proc. vol.585 (2000) pp.35-43
[2] W.Prusseit, G.Sigl, R.Nemetschek, J.Handke, A.Lunkermann, H.Kinder : ASC 2004. Oct. 4-8 (2004)
[3] W.Prusseit, G.Sigl, R.Nemetschek, J.Handke, A.Lunkermann, H.Kinder : CCA 2004 Kanagawa, Japan, Oct. 19-20 (2004)
[4] A.Villaume, A.Antonevici, D.Bourgault, X.Chaud, J.P.Leggeri, L.Porcar, A.Sulpice, C.Villard : presented at EUCAS 2005
[5] M. Sugano, K.Osamura, W.Prusseit, R.Semerad, T.Kuroda, K.Itoh, T.Kiyoshi : Proceedings of Applied Superconductivity Conference, October 3-8, (2004)
[6] M. Sugano, K.Osamura, W.Prusseit, R.Semerad, K.Itoh, T.Kiyoshi : Supercond.Sci. Technol., October 18, (2005), S344-S350
[7] O.H.Wyatt, D.Dew-Hughes, Metals, Ceramics and Polymers (1974) pp.222-230