CRYO/02/027
February 26, 2002

Critical Surface for BSCCO-2212 Superconductor

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Summary

In this note we describe a simple parametrization for the calculation of the engineering critical current in BSCCO-2212. Typical parameters to be used for the material are reported. The critical surface is described as a function of applied field and operating temperature. Additional expressions are given for the critical temperature and field and current sharing temperature.

1. Introduction

High temperature superconducting tapes are entering the domain of practical applications. This is particularly true for Ag/BSCCO-2212 that is commerciasly available in tapes and strands of long length. A rational use of this superconductor requires that a proper parametrization is available for the engineering current density as a function of the external field and temperature. Suitable approximations have been derived in [1] and [2]. The purpose of this note is to summarise the results discussed in the above references and to give a simple expression for the critical surface, applicable in the domain of use of this material.

In this note we will use the following symbols for the critical parameters:

J_c	critical current density	(A/m^2)
$T_c(B)$	critical temperature	(K)
$T_{cs}(J,B)$	current sharing temperature	(K)
$B_c(T)$	irreversibility field	(T)
T_{c0}	maximum critical temperature at zero field	(K)
B_{c0}	maximum irreversibility field at zero temperature	(T).

Note that the irreversibility field is used here for scaling purposes, as this is more appropriate from the engineering point of view. In addition the following reduced parameters will be used:

$t = \frac{T}{T_{c0}}$ reduced temperature

$b = \frac{B}{B_c(T)}$ reduced field.

2. Critical Field

For HTS it is customary to define a maximum operational field, the irreversibility field, that can be much below the critical field of the material. Above the irreversibility field flux flow strongly limits current transport. For engineering purposes we can therefore use the irreversibility field in the same way as the upper critical field in LTS. A fit of the irreversibility field as a function of temperature is given by [2]:

$$B_c = B_{c0} e^{-\alpha t} \quad (1).$$

The expression above does not tend to zero for T approaching the maximum critical temperature T_{c0} (t approaching 1). The parameter α has however values such that B_c is small for $T = T_{c0}$ where Eq. (1) can be safely truncated setting $B_c = 0$.

3. Critical Temperature

As for the critical field, the engineering critical temperature is defined as the value of temperature where irreversible flux-flow starts. This corresponds to the inverse of Eq. (1):

$$T_c = \frac{T_{c0}}{\alpha} \log\left(\frac{B_{c0}}{B}\right) \quad (2).$$

As for Eq. (1) the limit condition for small value of the magnetic field is set artificially to $T_c = T_{c0}$.

4. Critical Current Density

The critical current density of BSSCO-2212 can be computed as follows [1]:

$$J_c = J_{cs} + J_{cw} \quad (3)$$

where two contributions are defined, the weak links J_{cw} and the strong links J_{cw}. The strong links current density is given by [2]:

$$J_{cs} = J_{cs0}(1-t)^{\gamma} e^{-\beta b} \tag{4}$$

where J_{cs0} is the value of the strong links current density at zero field and temperature.

The weak links critical current density drops sharply in an external magnetic field. Its dependence on field can be approximated by a Kim relation [1]:

$$J_{cw} \propto \frac{B_0}{B+B_0} \tag{5}$$

where the characteristic field B_0 has a small value (few to few tens of mT). The proportionality factor is assumed to follow the same temperature dependence as in Eq. (4) for the strong links, resulting in the following expression for the weak links current density:

$$J_{cw} = J_{cw0}(1-t)^{\gamma} \frac{B_0}{B+B_0} \tag{6}$$

where J_{cw0} is the value of the weak links current density at zero field and temperature.

To define the overall scaling of Eqs. (4) and (6) we introduce the value C_0 of the critical current at zero applied field and zero temperature and we define:

$$J_{cs0} = \chi\, C_0 \tag{7a}$$

$$J_{cw0} = (1-\chi)\, C_0 \tag{7b}$$

where the parameter χ is the ratio of the strong links current density to the total current density at zero field and temperature, and conveniently defines the split among weak and strong links.

In summary we have then that the total critical current density is given by:

$$J_c = C_0 \left[(1-\chi)(1-t)^{\gamma} \frac{B_0}{B+B_0} + \chi\,(1-t)^{\gamma} e^{-\beta b} \right] \tag{8}$$

The above expression is numerically stable at zero field, but does not drop to zero at the critical field. However, with a proper choice of the constants in the equation, the resulting values are sufficiently close to zero in the proximity of B_c and can be safely truncated setting $J_c = 0$.

5. Current Sharing Temperature

The current sharing temperature T_{cs} is defined implicitly as the temperature at which the critical current density is equal to the operating current density J_{op}:

$$J_{op} = C_0 \left[(1-\chi)(1-t_{cs})^{\gamma} \frac{B_0}{B+B_0} + \chi (1-t_{cs})^{\gamma} e^{-\beta b} \right] \quad (9)$$

with the following definition of the reduced current sharing temperature:

$$t_{cs} = \frac{T_{cs}}{T_{c0}} \quad (10).$$

Equation (9) is non linear and can be solved at best with a bisection method.

6. Typical Parameters Values

Measured J_c data for Ag/BSSCO-2212 tape from [2] has been fit using the above equations. The result of the fit of the irreversible field and of the critical surface are shown in Figs. 1 and 2. The values of the constants to be used to parametrise the critical surface $J_c(B,T)$ are given in Tab. 1. Typical values for present state-of-the art superconductor can be obtained taking the parameters given there and an increased value for C_0 of the order of 1250 (A/mm^2).

Table 1. Typical values of the constants obtained fitting the parametrization discussed in this note to the $J_c(B,T)$ data on Ag/BSSCO-2212 tape reported in [2].

B_{c0}	(T)	465.5
T_{c0}	(K)	87.1
C_0	(A/m^2)	865.5×10^6
B_0	(T)	75×10^{-3}
α	(-)	10.33
β	(-)	6.76
γ	(–)	1.73
χ	(-)	0.55

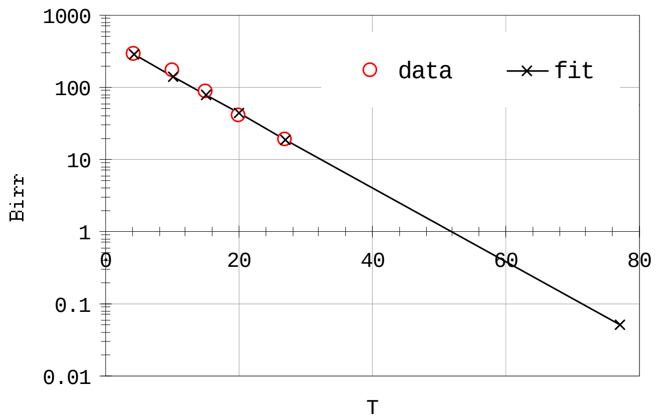

Figure 1. Fit of irreversibility field of Ag/BSSCO-2212 tape using Eq. (1). The data has been taken from [2].

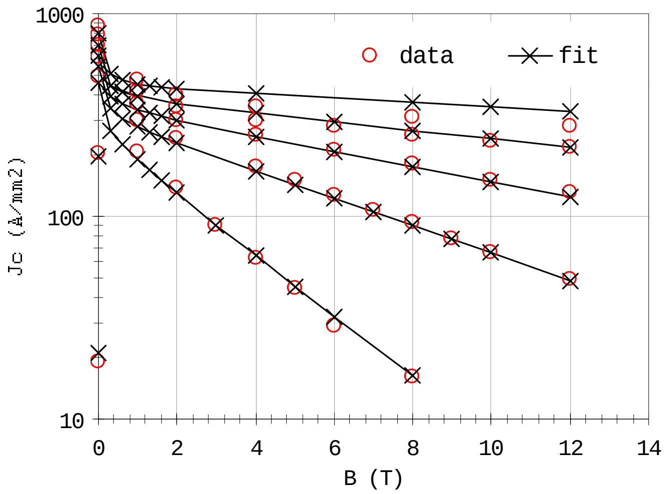

Figure 2. Fit of measured critical surface of Ag/BSSCO-2212 tape using the parametrisation proposed in this note. The measurements have been taken from the data reported in [2].

References

[1] D.C. van der Laan, H.J.N. van Eck, B. ten Haken, J. Schwartz, H.H.J. ten Kate, *Temperature and Magnetic Field Dependence of the Critical Current of BSCCO Tape Conductors*, IEEE Trans. Appl. Sup., **11**(1), 3345-3348, 2001.

[2] R. Wesche, *Temperature Dependence of Critical Currents in Superconducting Bi-2212/Ag Wires*, Physica C, **246**, 186-194, 1995.