

**Zeitschrift:** Helvetica Physica Acta

**Band:** 62 (1989)

**Heft:** 6-7

**Artikel:** Flux creep in high-T<sub>C</sub> superconductors

**Autor:** Fiorani, D.

**DOI:** <https://doi.org/10.5169/seals-116069>

#### **Nutzungsbedingungen**

Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften auf E-Periodica. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. Das Veröffentlichen von Bildern in Print- und Online-Publikationen sowie auf Social Media-Kanälen oder Webseiten ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. [Mehr erfahren](#)

#### **Conditions d'utilisation**

L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. La reproduction d'images dans des publications imprimées ou en ligne ainsi que sur des canaux de médias sociaux ou des sites web n'est autorisée qu'avec l'accord préalable des détenteurs des droits. [En savoir plus](#)

#### **Terms of use**

The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. Publishing images in print and online publications, as well as on social media channels or websites, is only permitted with the prior consent of the rights holders. [Find out more](#)

**Download PDF:** 17.01.2026

**ETH-Bibliothek Zürich, E-Periodica, <https://www.e-periodica.ch>**

## FLUX CREEP IN HIGH- $T_C$ SUPERCONDUCTORS

D. Fiorani

I.T.S.E., Area della Ricerca di Roma del CNR, C.P. 10, 00016  
Monterotondo Stazione, Italy.

### Abstract

The time decay of the zero field cooled magnetization was investigated for a  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+x}$  single crystal ( $T_C=85\text{K}$ ) at different temperatures. From the low temperature data, interpreted with a thermally activated flux creep model, an average pinning energy is derived for different magnetic fields applied parallel to the c axis (e.g.  $U_0=2.4 \cdot 10^{-3} \text{ eV}$  for  $H=1 \text{ kOe}$ ).

### Introduction

Hard type II superconductors are characterized by magnetic irreversibility and relaxation effects in the mixed state. The observation of these effects in high- $T_C$  superconductors was originally attributed to the existence of a glassy state [1], arising from a network of random weakly linked superconducting clusters, because of the qualitative similarities with the spin-glass properties (splitting between zero field cooled and field cooled susceptibility, non exponential decay of zero field cooled and remanent magnetization, field/temperature irreversibility line de Almeida Thouless like ... ).

Although this description seems to be reasonable for sintered materials, constituted by weakly linked superconducting grains, it is presently believed that these properties can be interpreted, at least at low temperature, in terms of the thermally activated flux creep model [2].

The above mentioned properties are common to the conventional superconductors, but a very important difference does exist: in high- $T_C$  superconductors there is a much more important degree of thermal activation for the flux motion, which manifests itself in a faster magnetic relaxation and then in a

more rapid decrease of  $J_C$  with increasing temperature.

The thermally activated flux motion is enhanced by two combined factors:

- a) the average pinning energy  $U_0$  is one or two orders of magnitude lower, because of the much smaller coherence length ( $U_0$  scales as  $H_C^{2/3}$ ) [2];
- b) the critical temperatures are almost one order of magnitude higher.

In this paper the results of critical current and relaxation measurements in a  $Bi_2Sr_2CaCu_2O_{8+x}$  single crystal are reported.

### Results and discussion

A single crystal ( $2.2 \times 1.7 \times 0.3 \text{ mm}^3$ ) grown by the flux technique [3] was selected for the measurements. The magnetic properties were investigated by AC susceptibility measurements, carried out by means of a mutual inductance bridge ( $H_{AC} \approx 1 \text{ Oe}$  at  $v=200 \text{ Hz}$ ) and by DC susceptibility and magnetization measurements, carried out by means of a commercial SQUID magnetometer.

The AC susceptibility curve, measured applying the field both parallel and perpendicular to the c axis, shows only one transition at 85 K, ascribed to the 2212 phase. No trace of a drop at 110 K could be detected, thus indicating the absence of any contribution from the higher  $T_C$  phase.

Magnetization cycles were performed at different temperatures applying the magnetic field parallel to the c axis. (Fig. 1). The lower critical field, estimated as the field at which deviation from the linearity occurs in the  $M$  vs  $H$  plot, is  $H_{c1} \approx 350 \text{ Oe}$  at 4.2 K.

With increasing temperature the irreversible regime of the magnetization cycles is rapidly restricted to low fields.  $J_C$  becomes strongly field dependent at temperatures so low as 20 K and vanishes at 30 K in presence of moderate fields.

The critical current in zero field was determined from the remanent magnetization at the end of the magnetization cycle by using the Bean formula for the critical state (a shape of a cylinder with a radius  $R=0.1 \text{ cm}$  was assumed).

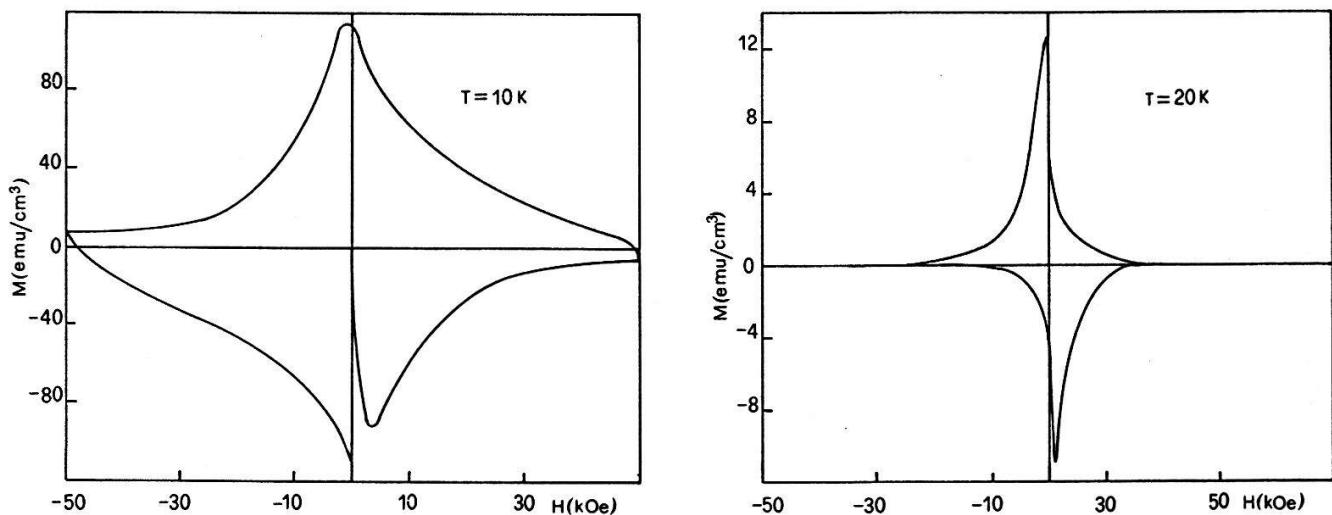


Fig. 1 Magnetization cycles

At 4.2 K the critical current  $J_{C//}$  is  $2.1 \cdot 10^6 \text{ A/cm}^2$ . The temperature dependence of  $J_C$  was satisfactorily described by the phenomenological law

$$J_C = J_C(0) (1 - T/T_C)^n$$

with  $n=8$ , as reported for YBaCuO [4]. The decrease of  $J_C$  with temperature is much more rapid than in conventional superconductors, where  $n$  ranges from 1 to 2.5. Such behavior, indicating an important thermal activation for the flux motion, implies pinning energies lower than those reported for conventional superconductors ( $U_0 \approx 1 \text{ eV}$ ).

We have determined the average pinning energy measuring the time decay of the zero field cooled magnetization at 4.2 K for different values of the external magnetic field (1 kOe; 3 kOe; 10 kOe) applied parallel to the c axis. The decay was found to be logarithmic (Fig. 2), in agreement with the classical flux creep model [2]. The fields we have used are lower than  $H^*$ , the field such that flux first penetrates through the sample. In such conditions and for  $KT/U_0 < 1$ , the relaxation rate of the magnetization for a cylinder is given, in first approximation, by the relation [4]:

$$\frac{d(4\pi M)}{d\ln t} = \frac{H^2}{H^*} \left[ 1 - \frac{2H}{3H^*} \right] \frac{KT}{U_0}$$

which is derived by substituting the expression for the temperature decrease of  $J_C$  ( $J_C = J_{Co} [1 - (KT/U_0) \ln(t/t_0)]$ ) [5] in the Bean equation for the critical state ( $H^* = (4\pi J_{Co} R)/10$ ) [6]. The deduced average pinning energy decreases increasing the applied field:  $U_0 = 2.4 \cdot 10^{-3}$  eV for  $H = 1$  kOe;  $U_0 = 1.0 \cdot 10^{-3}$  eV for  $H = 3$  kOe;  $U_0 = 8 \cdot 10^{-4}$  eV for  $H = 10$  kOe).

The relevant effect of the temperature is shown in Fig. 2, where the time decay of the magnetization  $M/M_0$  is reported at 4.2 K, 10 K and 15 K for a field  $H = 10$  kOe applied parallel to the c axis. At  $T = 15$  K after one hour the magnetization is reduced to  $\approx 48\%$  of the initial value. These data are consistent with the vanishing of  $J_C$  at low temperature in moderate fields, as shown by the reversible magnetization above  $\approx 30$  K.

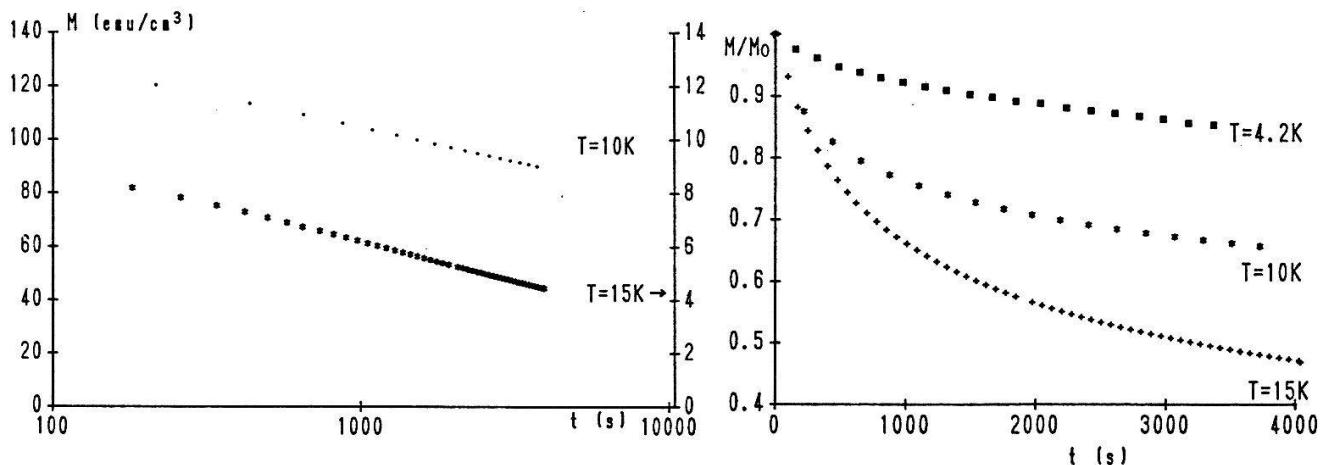


Fig. 2 Time decay of the magnetization for  $H = 10$  kOe

### Conclusions

The results indicate strong magnetic relaxation for the zero field cooled magnetization of a BiSrCaCuO single crystal. With respect to YBCO, higher relaxation rates and smaller pinning energies (almost an order of magnitude) [7,8] are found. Furthermore, a stronger field dependence of  $J_C$  is observed above  $\approx 20$  K, giving rise to a wider reversible regime. These data are consistent with observations of strong dissipative effects (flux

flow resistivity) [9] and with evidences of vortex lattice melting in moderate fields at temperatures much lower than  $T_c$  [10].

These differences, which involve the nature of the pinning centers, could be due to the absence of twin planes in BiSrCaCuO. They act as anisotropic pinning centers in YBaCuO and then they could be responsible for the higher  $J_c$  and  $U_o$  anisotropy [8,9] with respect to BiSrCaCuO.

#### Acknowledgments

I wish to thank E. Agostinelli, G. Balestrino, P. Paroli and A.M.Testa for useful discussions and P. Filaci and R. Muzi for technical assistance. I am indebted to J. Tejada for discussions and his kind hospitality at the Departamento de Fisica Fonamental in Barcelona, where most of the experiments were performed.

#### References

- [1] K. A. Muller, M. Takashige and J. G. Bednorz, Phys. Rev. Lett. 58, 1143 (1987)
- [2] P. W. Anderson, Phys. Rev. Lett. 9, 309 (1962)
- [3] G. Balestrino, U. Gambardella, Y. L. Liu, M. Marinelli, A. Paoletti, P. Paroli, G. Paternò, J. Crystal Growth 92, 674 (1988)
- [4] Y. Yeshurun, A. P. Malozemoff, F. Holtzberg, J. Appl. Phys. 61, 5797 (1988)
- [5] A. M. Campbell and J. Evetts, Adv. Phys. 21, 199 (1972)
- [6] C. P. Bean, Review of Modern Physics 26, 31 (1964)
- [7] Y. Yeshurun, A. P. Malozemoff, T. K. Worthington, R. M. Yandrofski, L. Krusin-Elbaum, F. H. Holtzberg, T. R. Dinger and G. V. Chandrashekhar, Cryogenics 29, 258 (1989)
- [8] B. D. Biggs, M. N. Kunchur, J. J. Lin and S. J. Poon, Phys. Rev. B. 309, 7309 (1989)
- [9] R. B. Van Dover, L. F. Schneemeyer, E. M. Giorgy and J. V. Waszczak, Phys. Rev. B. 39, 4800 (1989)
- [10] P. L. Gammel, L. F. Schneemeyer, J. V. Waszczak and D. J. Bishop, Phys. Rev. Lett. 61, 1666 (1988)