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IRRADIATION EFFECTS FOR IN-SITU COMPOSITE CONDUCTORS

J. E. Ostenson, D. K. Finnemore, J. D Verhoeven, and E. D. Gibson
Ames Laboratory-USDOE* and Department of Physics
Iowa State University, Ames, Iowa 50011

and

C. L. Snead, Jr.,**
Brookhaven National Laboratory
Upton, New York 11973

Abstract

A series of high-performance in situ composite conductors have been studied to determine the detrimental effects of neutron irradiation on the upper critical field, the transition temperature and the critical current. For fluences up to 1×10^{18} n/cm^2, there is essentially no degradation of any of the superconducting properties. At 7×10^{18} n/cm^2, however, T_c has dropped to 13 K and at 10^{19} neutrons n/cm^2 T_c has dropped to 9 K. The ratio of H_{c2}/T_c is essentially constant at 1.0 T/K for fluences out to 1.3×10^{19} n/cm^2. The volume pinning force goes as $(1-b)^2$ for all samples indicating that shear in the flux line lattice controls J_c even for samples with T_c as low as 6 K.

Introduction

In situ superconducting composites have performance characteristics which make them attractive as a conductor material for large scale magnets in the 12 T regime. The critical current density of 6×10^4 A/cm^2 at 12 T, strain tolerance of 1.4% and ultimate tensile strength of about 1 GPa[1,2] all compare favorably with bronze process material.[3] In addition it appears that they can be produced on a large scale.[4] The primary difference between in situ and conventional material is that the superconducting filaments are much smaller (~70 nm thick) and they are discontinuous. This morphology might possibly alter the susceptibility of these materials to degradation in an irradiation environment so a series of experiments was carried out to determine these effects. We report here the change in the critical current density, J_c, the transition temperature T_c, and the upper critical field, H_{c2} with fluence.

Experimental

The neutron irradiations were preformed at the Brookhaven High Flux Beam Reactor. The wire specimens were sealed in 4-mm quartz tubes with 0.5 atm of helium gas. These were placed in the aluminum irradiation capsule and the capsule then filled with H_2O to facilitate good heat transfer. The temperature of the specimens during irradiation was estimated to be ~80°C. The neutron flux of the reactor was 1.3×10^{14} n/cm^{2}sec for neutron energies E > 1 MeV. If comparison is desired for the broader damaging neutron spectrum, the flux for neutrons with energy E > 0.11 MeV was 5.64×10^{14} n/cm^{2}sec.

Samples were prepared by a casting and drawing technique described earlier.[1] Measurements of T_c were made with a standard 4 probe resistance measurement in which a measuring current of 2 A/cm^2 was directed parallel to the long axis of the filaments. In addition, ac susceptibility measurements of T_c were made in which current was induced to flow around the circumference of the sample perpendicular to the long axis of the filaments. Critical current measurements were made in a Bitter type solenoid at the National Magnet Laboratory. Thermometry was done with germanium resistance thermometers for the zero magnetic field work. Because traces of superconductivity were seen at 19 K, a special calibration of the thermometry was carried out using a bulk Nb_3Sn sample which had been measured by other groups. The temperature scale proved to be correct. Carbon glass thermometeres were used for the high field work at the National Magnet Laboratory.

Results and Discussion

In broad outline, neutron irradiation changes the performance characteristics of in situ Nb_3Sn-Cu in much the same way as it changes bulk Nb_3Sn.[5] As shown in Fig. 1, T_c remains constant at 18 K out to about 2×10^{18} n/cm^2. Above this fluence a gradual decline in T_c begins and at 1.3×10^{19} n/cm^2, T_c is approximately 9 K. The corresponding values for bulk Nb_3Sn found by Sweedler et. al.[5] are very similar. The results found by Snead et. al.[6] for bronze-Nb_3Sn filamentary wires are nearly the same.

For inhomogeneous and highly anisotropic materials such as these, it is important to point out that the transitions are fairly broad and the value of T_c depends on how it is measured. For all of the samples, measurements were made by a standard four probe technique with a measuring current density of 2 A/cm^2 parallel to the long axis of the filaments and the wire. The transition widths for a variety of samples range from 0.5 to 1.5 K for the temperature between the points where the resistance is 10% and 90% of the normal state resistance. This is typical for in situ materials.[1] The differences between the two different samples represented by the open and closed circles accurately reflect the reproductibility from sample to sample. The superconducting to normal transitions for these same samples also have been measured by an ac

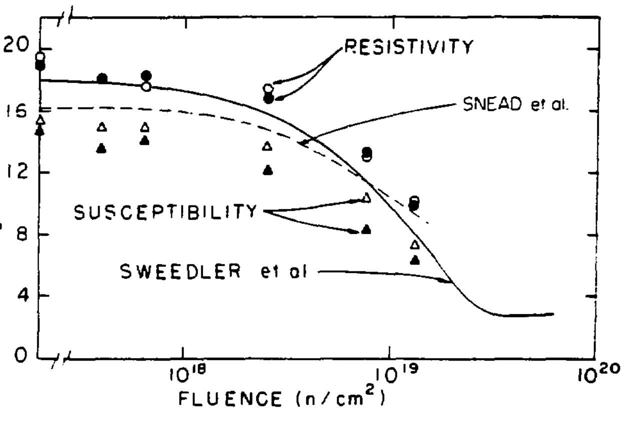

Fig. 1. Change in T_c with fluence.

susceptibility technique in which currents are induced around the circumference of the wire perpendicular to the long axis of the filaments. This means that the measuring current must cross through the bronze barriers separating the filaments so this susceptibility measures the onset of appreciable proximity coupling. The results for measuring fields of 0.1 mT at 100 Hz

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shown by the open and closed triangles of Fig. 1, indicate that the samples do not show shielding against magnetic flux entry until temperatures approximately 4 K lower than the onset of superconductivity in the filaments. The susceptibility transition widths are about the same as for resistive transitions ranging from 0.5 to 2.0 K wide for the 24 samples involved in this study.

The key performance characteristic for use in magnets is the magnetic field dependence of J_c. These data are found to follow a relation of the form $J_c = AB^{-1/2}(B_{c2}-B)^2$ as expected if the shear modulus of the flux line lattice, C_{66}, controls the volume pinning force.[7] To show this, the data are plotted as $J_c^{1/2}B^{1/4}$ vs B in Fig. 2 and they are roughly linear on this plot for the full range of fluence. For fluences up to 6×10^{17} n/cm^2, J_c and H_{c2} increase, presumably because the irradiation reduces the mean free path of the electrons in the Nb_3Sn. At higher fluences the damage is sufficient to lower T_c appreciably and both H_{c2} and J_c are reduced. The value of H_{c2}/T_c is approximately 1 T/K for the full range of fluence as emphasized in Fig. 3. The H_{c2} data in Fig. 3 were taken from an extrapolation of the Kramer plot of Fig. 2 to $J_c^{1/2}B^{1/4}=0$. This rise in J_c for low fluence is similar to results for a single core Nb_3Sn filament reported earlier.[5,6]

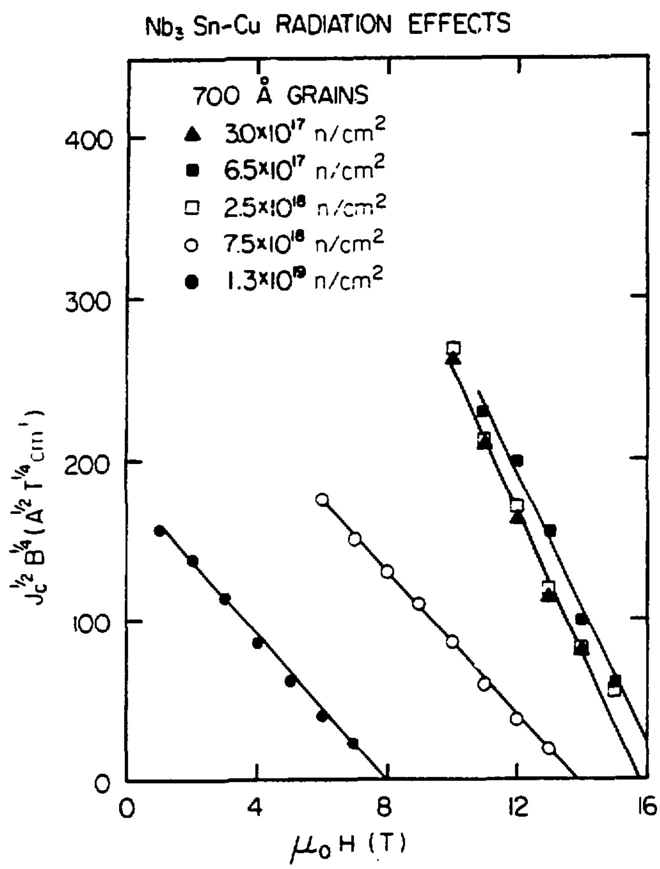

Fig. 2. Critical current density vs. magnetic field.

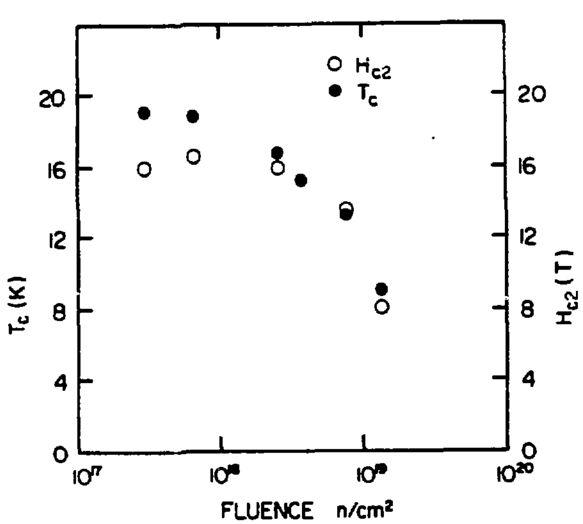

Fig. 3. Comparison of H_{c2} and T_c.

Conclusions

The performance characteristics of <u>in situ</u> prepared superconducting composites change with neutron irradiation in a manner very similar to bulk Nb_3Sn. The J_c values actually improve for fluences up to 2×10^{18} n/cm^2 but serious degradation of J_c occurs for fluences above 5×10^{18} n/cm^2.

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References

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1. J. J. Sue, J. D. Verhoeven, E. D. Gibson, J. E. Ostenson, and D. K. Finnemore, Acta Met. 29, p. 1791, 1981.

2. J. Ekin, IEEE Trans. Magn., Vol. MAG-15, p. 197, 1979.

3. M. Suenaga, W. B. Sampson and T. S. Luhman, IEEE Trans. Magn., Vol. MAG-17, p. 646 1981.

4. C. Spencer, E. Adam, E. Gregory, W. Maranchik, and C. Z. Rosen, IEEE Trans. Magn., Vol. MAG-17, p. 257, 1981.

5. A. R. Sweedler, D. G. Schweitzer and G. W. Webb, Phys. Rev. Lett. 33, p. 168, 1974 .

6. C. L. Snead, Jr. and M. Suenaga, Appl. Phys. Lett. 37, p. 659, 1980; C. L. Snead, Jr., D. M. Parkin and M. W. Guinan, J. Nuc. Mat. 103, p. 749, 1981.

7. E. J. Kramer, J. Appl. Phys. 44, p. 1360, 1973.

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