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SIZE EFFECT AND CRITICAL TRANSPORT CURRENT IN TITANIUM (22 at % NIOBIUM)

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The dependence of the critical transport current density on conductor size has been measured for the superconductor, Ti (22 a/o Nb), in transverse fields up to 93 kgauss. For samples with as similar metallurgical histories as possible, it is found that the critical current is proportional to the cross sectional area for samples 0.0024 inch to 0.0501 inch in diameter. More important, the field dependence found for critical current densities is given by:

$$J_c = A_o/b_o \; e^{-B/b_o} + C_o \quad ,$$

where B is the applied transverse magnetic field.

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Critical currents have been measured for Ti (22 a/o Nb) in transverse fields up to 93 kgauss for samples ranging in size from 0.0024 in. to 0.0501 in. diameter. The conclusions reached by this study are that the current density is independent of sample diameter and that an exponential dependence of the current density on magnetic field is in good agreement with all the data.

Since 1962, very little work has been reported on the size dependence of Type II superconductors.(1) Betterton found for NbZr that "small" wires could sustain critical current densities up to five times the critical current densities for "large" wires.(2) His samples ranged in size from 0.002 in. to 0.015 in. and were prepared by similar metallurgical processes. Aron has also investigated the NbZr system and, by expressing his results as:

$$I_c \sim d^p \quad , \qquad \ldots(1)$$

where I_c is the critical current and d is diameter, found that $p \cong 2$ below 50 kgauss but drops to about $p \cong 1$ at 65 kgauss.(3) One objective of the

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present work is to determine p for Ti (22 a/o Nb).

Another objective of this study is to determine the field dependence of critical currents for Ti (22 a/o Nb). The results are discussed in terms of two critical state relations introduced by Kim(4,5) and Fietz(6). Kim's critical state relationship, determined from experiments with cylindrical samples of NbZr, Nb_3Sn, and NbTa, is:

$$J_c(B) = \frac{A}{B + b_o} \quad . \qquad \ldots(2)$$

Fietz's relation for NbZr is:

$$J_c(B) = \frac{A}{b_o} e^{-B/b_o} + C_o \quad , \qquad \ldots(3)$$

where J_c is the critical current density, B is the applied field, and the other quantities are constants for specific systems.

EXPERIMENTAL PROCEDURE

Samples of Ti (22 a/o Nb) with as similar metallurgical histories as possible for a given series were prepared with diameters ranging from 0.0024 in. to 0.0501 in. The metallurgical history of one series of samples was altered to produce a lower $J_c(B)$ value than the other series. This was to enable the detection of any joint resistance, sample motion, or effects which might confuse a basic size dependence interpretation. The preparation of two different series of samples (low and high $J_c(B)$) also provided a more general check on the validity of Equations 2 and 3. Most samples were mounted with copper press joints (Figure 1a). A few larger diameter samples ($>$ .030 in.) were fabricated into stabilized cables(7,8) (Figure 1b). Each cable consisted of annealed Cu stranded around one Ti (22 a/o Nb) conductor. Cables were always potted in solder. A few samples were tested with simple solder joints. Since the tests were limited by a 1000 ampere supply, it was impossible to obtain critical transport current densities in low magnetic fields for larger diameter wires.

All measurements between 30 kgauss and 70 kgauss were performed at the Stanford Linear Accelerator's partially stabilized 2-7/8 in. I.D. superconducting solenoid.(9) Tests above 70 kG were performed at the National Magnet Laboratory. All measurements were performed at 4.2°K.

RESULTS

It is seen in Figure 2 (Curve A) that for Ti (22 a/o Nb) the critical transport current density is not a function (within ± 10%) of size between 0.0024 in. to 0.048 in. in diameter. The plot in Figure 2 (Curve B) shows that the critical transport current is not a function (± 5%) of size between 0.010 in. to 0.050 in. in diameter. Thus, two widely different series of samples (Curves A and B) exhibit no dependence of current density on area. The fact that the high $J_c(B)$ (Curve A) data had larger fluctuations than the lower $J_c(B)$ (Curve B) data is not surprising in that on the average 25 times more power was dissipated in the joints for the Curve A samples than for Curve B samples. The Lorentz force on the superconductor and joint was 5 times larger for Curve A samples than for Curve B samples. Since any sample is more sensitive to motion at high fields, the larger Lorentz forces on Curve A samples presented more of a mount problem and introduced a larger data scatter than for Curve B samples. In addition, a 0.05 in. diameter wire was tested and then etched to a diameter of 0.008 in. The etched sample carried the same critical transport current density as did the original sample.

The critical transport current was taken to be that current where an abrupt change of voltage across the superconductor would occur.(4,5) Well shielded voltage probes always measure less than 10^{-6} volts until the abrupt transition to the normal state, thus providing no evidence of flux flow(4,5) prior to the abrupt normal transition. It should also be noted that the critical currents for stabilized cable samples were identical to short sample currents unless the short sample joint resistance of the superconductor to normal metal (Cu) was too high.

The critical state equation found in this present work for both series samples is given by Equation 3, except at high fields near H_{c_2} (which is 100 kgauss at 4.2°K for Ti (22 a/o Nb)).(10) For Ti (22 a/o Nb), Kim's relationship, Equation 2, is valid for fields below 40 kgauss. Equation 3 has no recognized fundamental physical significance, as far as we can determine. It should be commented that for most TiNb alloy systems which have been investigated the above form is correct with C_o very small or zero. The constants for Equation 3 are given in Table I.

DISCUSSION

It is thought that one of the reasons for the difference between the size dependence of NbZr and Ti (22 a/o Nb) is that pinning centers were introduced by different means. Ti (22 a/o Nb) as reported here was given a heat treatment process similar to that described by Vetrano and Boom.(11) The heat treatment is also thought to provide flux pinning sites by precipitating out small regions of "α" phase. If, as hypothesized, such precipitates are responsible for pinning sites, then they should be uniformly distributed throughout the superconductor volume and result in a super current which is proportional to the cross sectional area.

The form of Equation 3 fits various binary superconducting systems with different constants. It has so far fit the following systems: NbTa(12), NbZr,

Table I

Empirical Constants

Material	Curve	A_o/b_o	b_o	C_o
Ti (22 a/o Nb)	Curve A, Fig. 2	1.1×10^6 amps/cm^2	25 kG	0
Ti (22 a/o Nb)	Curve B, Fig. 2	4.7×10^5 amps/cm^2	15.1 kG	$.136 \times 10^5$ amps/cm^2
NbZr(6)	Coil #1	2.4×10^5 amps/cm^2	3.6 kG	$.79 \times 10^5$ amps/cm^2
NbZr(6)	Coil #2	2.3×10^5 amps/cm^2	4.6 kG	$.48 \times 10^5$ amps/cm^2

Fietz's parameters for NbZr are listed for comparison purposes.

NbSn and Ti (22 a/o Nb). It is interesting to note that Kim's critical state equation is given by the first term in the expansion of Equation 3. The general applicability of Equation 3 is supported by data from both high and low $J_c(B)$ samples of Ti (22 a/o Nb).

The practical implications of part of this work are that with Ti (22 a/o Nb) and with other similarly prepared alloys it is now possible to replace many small conductors with one large conductor. For example, stabilized cables can be constructed in which one large Ti (22 a/o Nb) wire replaces many smaller wires, without loss in current capacity.

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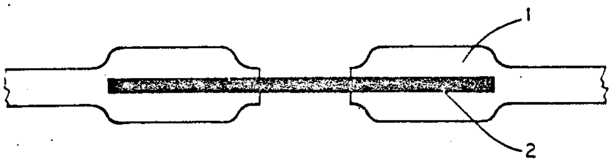

FIG. 1a

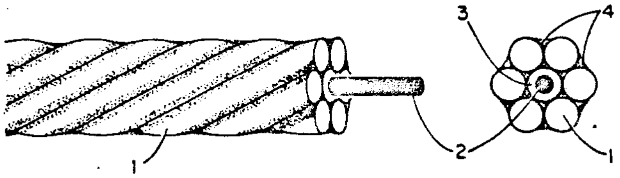

FIG. 1b

FIG. 1a

1 - Cu COLD WELD JOINT

2 - SUPERCONDUCTOR

FIG. 1b

1 - Cu CONDUCTOR

2 - SUPERCONDUCTOR

3 - Cu

4 - SOLDER

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FIGURE 1 Sample Mounts

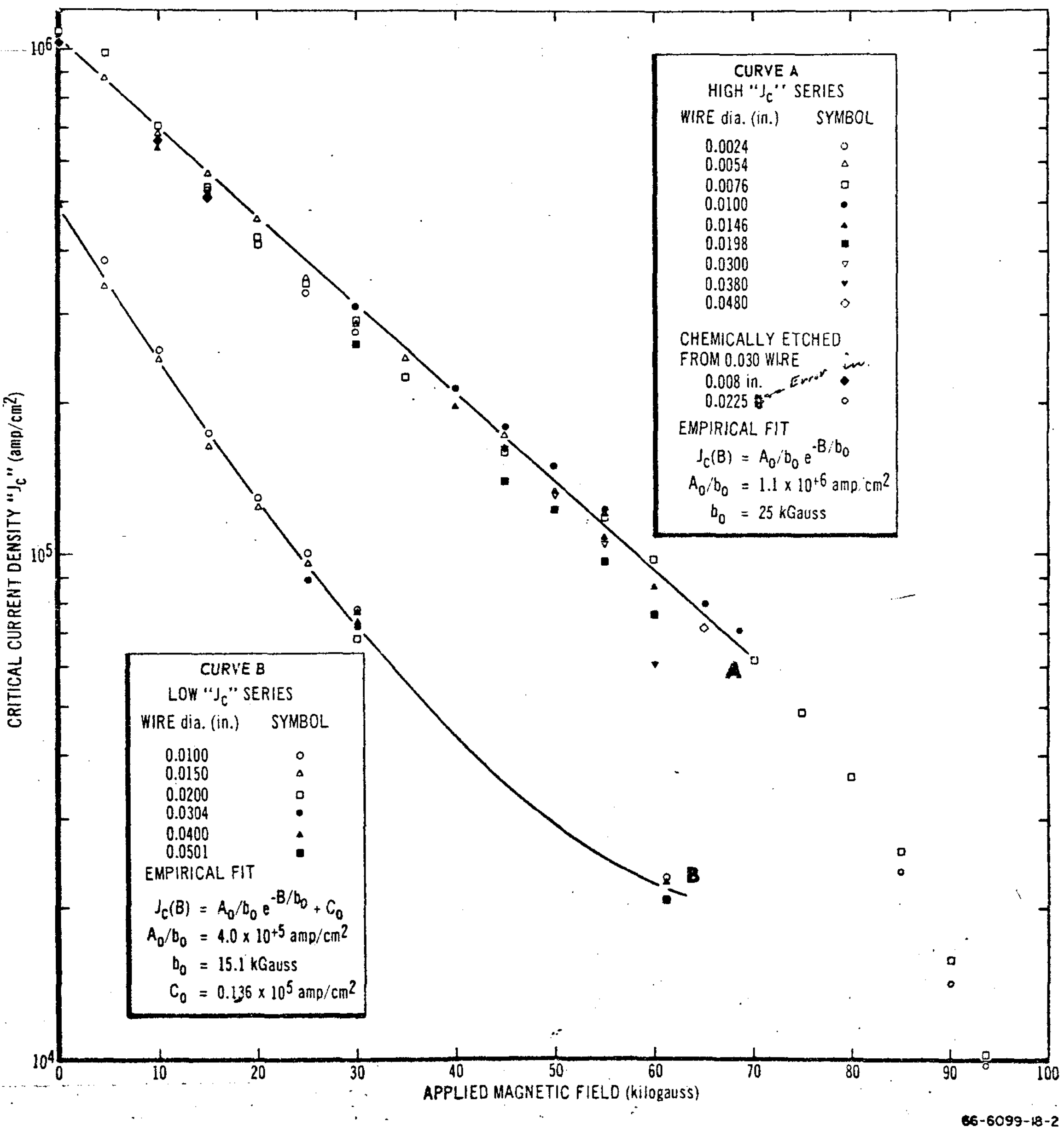

FIGURE 2 Current Density Versus Transverse Field at 4.2°K.

Not all of data plotted for reasons of clarity; maximum and minimum J for a given field are always shown.