SURFACE NUCLEATION AT ABRADED SUPERCONDUCTOR SURFACES*

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Recent experiments described in the literature show that surface abrasion results in the persistence of superconductivity at enhanced magnetic fields. The suggestion has been made that the abrasion alters the boundary conditions at the superconductor surface, thus raising the surface nucleation field. Our results on In-0.7% Bi alloy foils show that this behavior is not related to conditions at the specimen boundary, but rather to the presence of a layer of severely deformed material.

It is well established that for superconductors with $\kappa \lesssim 0.42$ surface nucleation may occur at applied magnetic fields exceeding the critical field for bulk nucleation of superconductivity.[1,2] A number of experiments,[3-5] however, indicate surface nucleation fields in excess of the theoretical prediction[1] of $H_{c3}=2.38\kappa H_c$ for surfaces in parallel fields. An extreme case is that of severely deformed Nb wire, where $H_{\text{nuc}}\approx 4H_{c3}$; such behavior is not apparently connected with surface effects.[5] Similarly the high-field resistive properties of Nb-Zr alloys may also be a heterogeneous phenomenon, not surface related.[6] Deformation of the surface itself may also markedly increase the nucleation field.[3,4] It has recently been suggested by Fink and Joiner[4] that the increase in surface nucleation field due to surface abrasion may be due to changes in the boundary conditions at the surface, in particular, the slope of the order parameter. To confirm this suggestion experiments were conducted by these authors on In-0.7% Bi alloy foils with and without surfaces abraded by crocus paper. Increases in both T_c and the nucleation field were noted.[4]

A simple alternative explanation for such observations is the presence of highly localized intense plastic deformation caused by the abrasion with no reference to the surface at all. We have performed experiments (which we shall presently describe) which duplicate the results of Fink and Joiner even when the deformed layer is inside the specimen and not near the surface at all. In addition, we find that actual modification of the order parameter at the surface, with or without deformed layers, do not alter the results.

Our In-0.7% Bi alloy ($\kappa\approx 0.37$) was made from high-purity materials and melted under vacuum. The alloy was then rolled to a thickness of about 0.015 in. between Mylar sheets to avoid contamination. The foils were then flattened between polished aluminum plates with no further reduction in thickness. A 3-day anneal was performed in a constant-temperature bath held at 130°C. The samples were tested in a four-point probe which contacted only one side of the foil. A voltage criterion of 1 μV/cm was used to determine the critical current. Specimens were tested with foil surface and current parallel to the magnetic field.

In Fig. 1 are data for a foil before and after abrasion; allowing for the lower temperature in our case, the results are similar to those of Fink and Joiner.[4] About three quarters of the samples apparently had higher homogeneity as the transition at H_c before abrasion was much more abrupt, as shown in Fig. 2. In order to place the abraded layer in the center of the specimen, foils were rolled together in jeweler's rolls. (This procedure, particularly for soft foils, bonds the sheets completely, even with small thickness reductions.) Before rolling, we abraded (1) none, (2) one, and (3) both of the surfaces to be bonded;

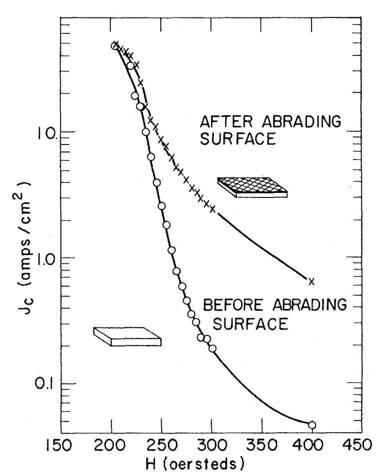

FIG. 1. J_c vs H for annealed In-0.7% Bi foil before and after one surface was abraded. Normal-state current density has been subtracted. $T=1.572$°K.

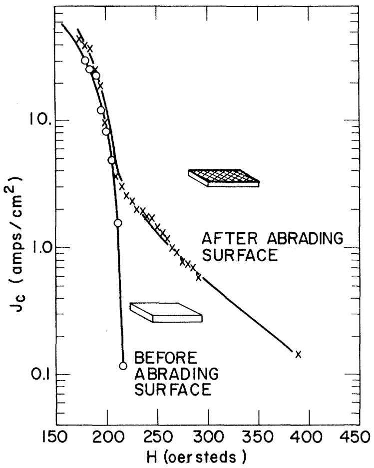

FIG. 2. Same measurement as for Fig. 1 but using a more homogeneous sample. $T = 1.338°K$.

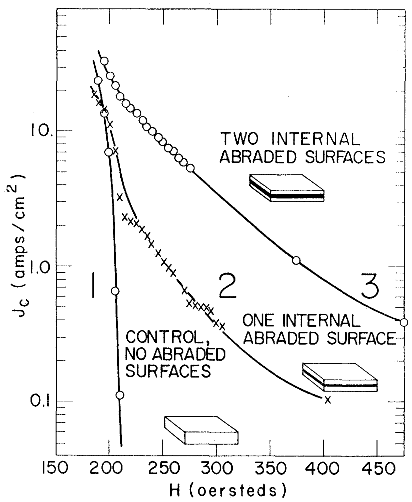

FIG. 3. J_c vs H for three different annealed In-0.07% Bi foil sandwiches. $T = 1.572°K$.

Fig. 3 shows the results of our measurements on these specimens. Abrasion was tried with a variety of materials. Steel wool distorted the foil least, and the data reported therefore correspond to steel-wool abrasion; crocus paper gave us the same results. The control experiment, curve (1) in Fig. 3, is within our experimental error identical to the "before-abrasion" curve in Fig. 2, demonstrating that the effect of our rolling procedure on J_c is negligible. As further controls, curve (2) in Fig. 3 used the abraded sample of Fig. 2 and a similar unabraded foil. Curve (3) in Fig. 3 used the abraded sample of Fig. 1 and another very similar specimen (i.e., a specimen with a similar curve of J_c vs H. It is apparent, when comparing Figs. 1-3, that the high-field "tail" exists whether or not the abraded layer is at the surface.

As a further test of the hypothesis that boundary conditions are not associated with such behavior, we abraded specimens similar to those of Figs. 1 and 2, with similar changes in properties; we then electroplated copper on the surfaces and retested. The results were unchanged by the copper layer, which should drastically depress the order parameter at the specimen surface.

It is not surprising that abrasion should cause such behavior, as mechanical abrasion is known to cause extremely severe local plastic deformation. The deformed layer may extend in soft metals to a distance of many microns, indeed, a significant part of a millimeter.[7] In fact, if burnishing occurs during abrasion, an amorphous (or nearly so) "Beilby layer" about 50 Å thick may occur in addition on the surface.[8] The properties of such a layer may be markedly different from the bulk (e.g., by "phonon softening").[9] Although the range of coherency is in this case much larger than 50 Å, the small shifts in T_c (ca. 0.02°K) observed may be due to the presence of a Beilby layer rather than the much thicker plastically deformed zone.

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