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Internal Stresses in Wires for High Field Magnets

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Abstract

The codeformation of Cu-Ag or Cu-Nb composite wires used for high field magnets has a number of important microstructural consequences, including the production of very fine scale structures, the development of very high internal surface area to volume ratios during the drawing and the storage of defects at interphase interfaces. In addition, the fabrication and codeformation of phases which differ in crystal structure, thermal expansion, elastic modulus and lattice parameter lead to the development of short wavelength internal stresses. These internal stresses are measured by neutron diffraction and transmission electron microscopy as a function of the imposed drawing strain. The internal stresses lead to important changes in elastic plastic response which can be related to both magnet design and service life and these aspects will be described in detail.

Introduction

The use of codeformation of in-situ composites such as those based on Cu-Ag or Cu-Nb is a very effective method of producing high strength-high conductivity wires for use in high field magnets [1-5]. The high strength of the materials is provided by very fine scale structures, very high internal surface area to volume ratios and the defects stored at interphase interfaces in the materials. Such structure can be produced by co-deformation of two-phase materials. The codeformation of two phases may also introduce short wavelength internal stresses, since two phases usually have different crystal structures, elastic modulus and lattice parameter. Moreover, fabrication two phases composite, such as casting or hot extrusion, may also introduce internal stress, due to the difference in the lattice parameter and thermal expansion of the two phases. We have measured internal stresses by neutron diffraction and other methods as a function of the imposed drawing strain. We have related the internal stresses to the changes in elastic plastic response and to both magnet design and service life.

Experimental Methods

Fabrication methods for Cu-Ag and Cu-Nb can be found in [6]. Materials were examined using a variety of metallographic methods. Scanning Electron Microscopy (SEM) samples were firstly sectioned by a low speed saw and then cold-mounted, polished, and etched in a solution of 30% nitric acid in ethanol. Samples for neutron reflection examination were machined to the rods of same sizes (4mm in diameter and 50mm in length) to avoid absorption effects. For comparison, samples of cold work strain 0.71 were prepared with different diameters and with annealing. Tensile testing was done at 25°C and -196°C using an MTS machine at an initial strain rate of 10^{-4} sec^{-1} .

Results and Discussions

Fig. 1. SEM second electron image (cross-section) showing the fine microstructure of the drawn Cu-25wt%Ag sample with strain of 1.

The microstructure of Cu-Ag after drawing is shown in Figs. 1. The SEM image taken from a sample with a drawing strain of 1 (drawing strain $\epsilon_d = 2 \ln(D_0/D_\epsilon)$, D_0 and D_ϵ are the original diameter of the wire and the diameter of the wire at strain of ϵ , respectively.) shows the combination of proeutectic Cu dendrites and the lamellar eutectic transformation product. As the drawing strain increases, both the dendrite spacing and the inter-lamellar spacing between Cu and Ag in the eutectic region decrease. The SEM images in a

longitudinal direction (parallel to the drawing direction, not showing in this paper) demonstrate that the Cu and Ag phases were aligned along the drawing direction when the materials were strained further. Similar microstructure was observed in cold drawn Cu-Nb conductors.

The radical internal strains measured by neutron reflection of Cu-Ag after different drawing strains are shown in Fig. 2. The internal strains are different in different orientations in both phases. Fig. 2 also shows that the radical residual strains in Cu and Ag are in compression and tension, respectively.

Fig. 2. Radical internal strains of Cu and Ag in Cu-24wt%Ag at different drawing strains.

In Cu-Nb samples, the radical internal strains, and therefore the internal stress, measured by neutron reflection are significantly higher than in Cu-Ag. Similar to Cu-Ag system, the internal strains are different in different orientations in both phases. However, the radical internal strain patterns in Cu-Nb are more complicated.

The internal strains or stresses resulted in the rounding of the stress-strain curves in both composite materials. The rounding of the stress-strain curve is more pronounced in Cu-Nb composites, since larger internal strains were observed. After fatigue tests, a sharper transition from elastic deformation to plastic deformation was observed. The change of the deformation behavior of the composites after fatigue can be related to the decrease of the internal stress in the composite. A shape transition from elastic deformation to plastic deformation makes determination of the yield strength more accurate and simplifies the design of the magnet.

Summary

The codeformation of Cu-Ag or Cu-Nb composite wires used for high field magnets produces very fine scale structures, very high internal surface area to volume ratios during the drawing and the storage of defects at interphase interfaces. The codeformation of Cu-Ag or Cu-Nb, leads to the development of short wavelength internal stresses and strains. Larger internal strains were observed in Cu-Nb composite than in Cu-Ag. The values of internal strains are different in different orientations. Therefore, the deformation of the composite is anisotropy. The internal stresses lead to the rounding of the stress-strain curve.

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