STRAIN DEPENDENCE OF THE CRITICAL PROPERTIES OF Nb3Sn: POLYCRYSTAL ANALYSIS, INVARIANT STRAIN FUNCTION

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Introduction

A calculation has been developed that relates the strain dependence of the critical properties of Nb3Sn to changes in the phonon frequency distribution that occur in the single crystals of Nb3Sn as a result of the application of the strain. The calculation is made using the Kresin equation for the critical temperature. The coupling constant and the characteristic frequency that enter the Kresin equation are computed over wave-vector space for Nb3Sn single crystals and include the three dimensional phonon frequency distribution. The effect of strain enters through the change in the three dimensional frequency distribution induced by the change in strain energy and stiffening of the crystal as a result of the applied strain. The calculation, based on single crystal concepts, reproduces the general characteristics of strain dependence in Nb3Sn. This General Invariant Analysis is general in the applied strain tensor and in crystal orientation, and has now been applied to polycrystalline material. The analysis involves detailed numerical calculations over wave-vector space. An analytic expression has now been derived which contains the essential results of the numerical calculations in the form of a general invariant strain function.

Analysis

The invariant strain analysis has been generalized to a polycrystalline analysis by including explicitly the tensor transformations of the applied strain over the full range of crystal orientations characteristic of a polycrystalline material. The existence of grain orientation in a polycrystalline material introduces the possibility that strain sensitivity is a function of grain orientation. If that were the case, then the strain dependence of the critical properties would vary among the various grains in a sample, with the critical properties of some crystal orientations being affected more than others. As a result, any initial distribution of the critical properties would spread, and therefore the distribution would be seen as having strain-dependence. This possibility was examined through the resistive transition of the critical temperature, which was studied as a percolation phenomenon. The slope of the resistive transition with temperature was found to be related to the distribution of Tc, and therefore the strain dependence of the slope of the resistive transition is a measure of the strain sensitivity of the distribution of Tc. A review of the literature revealed inconsistency in the available data, and focused the need for additional data to determine whether strain sensitivity in Nb3Sn is a function of grain orientation.

In further work, using the assumption of anisotropic strain-energy, an analytic expression for strain-dependence was derived as a function of the scalar invariants of the strain tensor. The resulting strain function provides a generalization of the classical one dimensional description of strain behavior. In the classical picture, the Nb3Sn is initially in a state of compression as the result of thermal differential contraction from cooldown. In particular, the axial compression along the direction of the wire is called the precompression. Under applied tension, the precompression is gradually relieved until the axial compression is reduced to zero, and that point is interpreted as corresponding to the maximum of the critical properties. In the new generalized picture, the initial state of strain is three dimensional. The maximum of the critical properties occurs at the point where the applied tension reduces the second and third strain invariants to zero. At the maximum, there remains hydrostatic compression, including compression in the axial direction. The generalized Invariant Strain Function is applicable to general strain loading, and to general configurations of conductor including round wire and flat tape, and is suitable for incorporation into detailed analysis of strain dependence at the filament level by Finite Element Analysis.

References