MICROSTRUCTURE AND ELECTROMAGNETIC PROPERTIES OF HEAVILY COLD WORKED CU-20 WT.%NB WIRES

MAX-PLANCK PROJECT REPORT

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Report abstract

Fiber or ribbon reinforced in-situ metal matrix composites (MMCs) consisting of Cu and 20 wt.% Nb can be produced by large strain wire drawing. The microstructure of the composites is investigated by means of optical and electron microscopy. The normal and superconducting properties of the MMC wires in the presence of external magnetic fields are examined and compared to the electromagnetic properties of pure Cu wires. The findings are discussed on the basis of the microstructural changes during deformation. The current results substantiate that the amount of internal boundaries and the filament spacing have considerable influence on the normal and superconducting properties of Cu-20%Nb.

Zusammenfassung

Faserverstärkte in-situ Verbundwerkstoffe mit metallischer Matrix (MMCs) aus Cu und 20 gew.% Nb wurden durch hohe Drahtverformung hergestellt. Die Mikrostruktur der Verbundwerkstoffproben wurde mit Hilfe licht- und elektronenoptischer Mikroskopie untersucht. Die normal- und supraleitenden Eigenschaften der MMC-Drähte wurden unter dem Einfluß äußerer magnetischer Felder gemessen und mit den elektromagnetischen Eigenschaften reiner Cu-Drähte verglichen. Die ermittelten Daten werden auf der Basis der mikrostrukturellen Entwicklung im Verlauf der Verformung diskutiert. Die vorliegenden Ergebnisse belegen, daß der Anteil an inneren Grenzflächen und der Faserabstand einen beträchtlichen Einfluß auf die normal- und supraleitenden Eigenschaften von Cu-20%Nb haben.

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Short Project Introduction

Copper and Niobium have negligible mutual solubility in the solid state. Ribbon or fibre reinforced in-situ processed metal matrix composites (MMCs) can hence be manufactured by large degrees of deformation, e.g. by wire drawing or rolling of a cast ingot.

Competitive binary systems of Cu with Ta, Cr, Mo or V show a similar thermodynamical behaviour, but exhibit considerable shortcomings as compared to Cu-Nb. The density of Ta, Cr, Mo and V strongly deviate from that of Cu so that gravitational segregation during solidification and the increase of the specific density of the final alloy deteriorate its potential for technological applications. Moreover, the melting temperatures of Ta and Mo are much higher than that of Nb which complicates the melting process.

Cu and Nb reveal almost equal densities (ρ_{Cu}=8890 kg/m^3 , ρ_{Nb}=8580 kg/m^3). Therefore gravitational segregation does not occur, practically. Increased Nb content leads to a decrease of ductility, i.e. of elongation to fracture, and to a degradation of electrical conductivity. Thus, an alloy containing 20 wt.% Nb appears to combine optimum electrical and mechanical properties. Cu - Nb composites have been under intensive investigation for the past 20 years mainly for the following two reasons:

1. The tensile strength of the deformed material is very high, in particular much greater than expected from the rule of mixtures. Several models have been proposed to explain the observed strength anomaly on the basis of microstructural mechanisms. The barrier model by Spitzig and coworkers attributes the strength to the difficulty of propagating plastic flow through the fcc-bcc interfaces (fcc=face centered cubic, bcc=body centered cubic). Funkenbusch and Courtney interpret the strength in terms of geometrically necessary dislocations owing to the incompatibility of plastic deformation of the bcc and fcc phase. In fact, both models succeed in describing the observed increase of strength assuming reasonable fitting parameters. In a recent approach, Raabe and Hangen have suggested a physical model which accounts for the observed dislocation structures and for the crystallographic textures of both phases. In such an approach the high tensile strength can be described nearly without using fitting parameters.

2. Owing to the observed combination of high strength and good electrical conductivity Cu-Nb based MMCs are considered as candidate materials for the production of highly mechanically stressed electrical devices such as application in long-pulse high-field resistive magnets. The potential use of these compounds, however, is much more widespread, e.g. applications in electronic devices in automobiles or as conducting frames in microelectronics are conceivable.

Whereas the microstructure of Cu-20%Nb and its electrical properties have been subject of thorough studies in the past, a rigorous correlation of microstructure and electromagnetic behaviour has not yet been obtained. The current study is primarily concerned with the investigation of the normal and superconducting properties of Cu-20%Nb compounds and the correlation of these properties to microstructure.

2 Experimental

The Cu and the Cu-20wt.%Nb alloys are melted in an induction furnace using a frequency of 10kHz and a power of 30kW. The Cu and the Nb both had an initial purity of at least 99.99 wt.%. Ingots of 18mm diameter were cast under an Argon atmosphere at a pressure of $0.8 \cdot 10^5$ Pa. According to the Cu-Nb phase diagram a melting temperature of at least 1750°C is recommended for Cu 20%Nb. Other researchers, however, reported the occurrence of a miscibility gap in the liquid phase due to the presence of interstitial foreign atoms, especially of H, N, C and O. Hence a temperature of at least 1830-1850°C was employed in order to assure complete dissolution of the Nb. A crucible and a mould of high purity graphite were used. The mould was preheated to about 600°C to ensure good fluidity and filling.

From the cylindrical ingots wires were produced by rotary swaging and subsequent drawing through hard metal drawing bench dies without intermediate annealing. The final diameter was 0.12 mm corresponding to a true strain of η=10 (ε=99.995%).

For investigation of the microstructure, scanning electron microscopy (SEM) and optical microscopy were employed. The resistivity measurements were carried out by means of the DC four-probe technique with currents between 10 and 100 mA. To study the normal and superconducting properties under externally imposed magnetic fields up to 15 Tesla within the temperature range 3K to 300K, an Oxford Instruments superconducting magnet was used. This magnet possesses a high field homogeneity and stability. A set of two samples, i.e. a Cu and a Cu-20%Nb wire having the same degree of deformation, were positioned in the center of the superconducting magnet in such a way that the direction of the external magnetic force was perpendicular to the current flow in the wires. The data were taken continuously during cooling. The cooling rate was controlled using a small heater, attached close to the samples, and by addition of a He exchange gas. For the measurement of the temperature a carbon-glass resistance sensor was applied. The values of the voltage drop were averaged from measurements with opposite polarity. The polarity was changed with a frequency of about 1Hz. Within the temperature range 300K to 3K, about 2000-3000 data points were taken. In the corresponding diagrams merely a small fraction of the total data is represented owing to the use of discrete symbols. Errors due to thermal expansion and thermal inequilibrium were neglected. The total error was estimated to be less than 3%.