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Fabrication Routes for High Strength-high Conductivity Wires

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Abstract

The development of suitable wires for magnet windings requires both the attainment of suitable combinations of properties (electrical conductivity and strength), the development of a production route capable of fabricating suitable quantity of wire of required dimension (5.2x7.6mm^2 cross-section and 120m in length) and a product with acceptable fabricability, joinability and service life.

In this survey, we will consider methods of producing suitable wire products by the codeformation of in-situ composites. This will include details of the quality control of the processing of Cu-Ag and Cu-Nb and the assessment of their detailed mechanical properties.

Introduction

The construction of a high field magnet is dictated by the available choice of conductor, insulation and reinforcement materials. The commercially available insulation and reinforcement materials currently appear to satisfy the design requirement of 100T quasi-continuous magnet. The conductor requires high mechanical strength (>1GPa), high conductivity (>72% I.A.C.S (International Annealed Copper Standard, 100%IACS=1.7241 μΩ cm), good elongation, forgiving plastic behavior, long fatigue life (>10,000 discharges), high resistivity ratio (ratio of resistivity at room temperature and low temperature, e.g. -196°C), suitable wire cross section (the largest one is 5.2x7.6mm^2) and length (>120m continuous length). No such conductor is currently commercially available yet. The work reported here encompasses the choosing of the elements to make a conductor, the selection of a suitable fabrication route, e.g. casting-forging-cold drawing or bundling-extruding-cold drawing, and the characterization of the mechanical properties and microstructure of the materials.

Materials Selection

In considering high strength conductors, attention has been paid to the metal matrix composite (MMC) conductors. The components of a MMC can be metal and metal or metal and ceramics. In metal-ceramic composite, ceramics acts as a reinforcement component. The ceramics can be in a form of particle of fibre. The ceramics currently used is either Al_2O_3 or SiC. The matrix is usually Cu because of its high conductivity and reasonable costs.

In metal-ceramic composite, Cu-X system has been studied. X can be an element or an alloy. In macroscopic MMC, X is usually the stainless steels.

A co-deformation of two components at high temperature provides the interfacial bonding between the phases. Both the strength level and the conductivity are governed by the relative volume fraction of the Cu and steel. In microscopic MMC, the properties of a composite depend not only on the volume fraction of the components, but also on the scale and morphology of the microstructures, interface area to volume ratios and the amount of defects stored at interphase interfaces. In order to obtain the required microstructure, significant amount of cold work has to be imposed. In the present paper, attention has been focused on co-deformation of composites such as Cu-Ag and Cu-Nb and development of fabrication routes for these materials.

Fabrication Routes

Different fabrication routes to produce Cu-Ag wires of the required properties and sizes have been developed and are summarized in Fig. 1. The total drawing strain, the ingot sizes and hot forging strain necessary to achieve the final strength level and cross-section should be estimated by assuming a linear work hardening rate which was deduced from previous work [1]. The continuously cast Cu-Ag billet of large diameter (usually larger than 100 mm if 5.2x7.6mm^2) was hot forged at a temperature below 625 °C to a smaller diameter. The temperature of the hot forging operation was chosen in order to decrease the dendrite size of the cast materials, avoid excessive grain growth, and to allow adequate ductility for forging. An annealing treatment may be introduced in order to homogenize the materials. After forging, surface of the billets has to be cleaned in order to remove the oxidized layer and other defects. One of the surface defects we have found was the inverse segregation of Ag to the surface. The material was cold drawn in round cross-section and finally to rectangular wires. In order to achieve the strength level of 1GPa, the total drawing strain was 4.8. Between the drawing, an intermediate heat treatment between 300-400°C may be introduced in order to remove the internal stress or possibly induce further precipitation.

Cu-Nb wires were fabricated by two methods. *In situ* composites were fabricated by a similar method to that used for Cu-Ag materials. Cu-Nb wires were also fabricated by bundling and deformation, using high purity Cu (99.99%) and Nb/Cu-Nb, as shown in Fig. 2. A Nb or Cu-Nb ingot was re-crystallized at high temperature (e.g., 1200°C for Nb) and extruded to the rod at 700-800°C. A composite billet made by inserting a Nb or Cu-Nb rod in a Cu can was evacuated and extruded to a rod of 20-30 mm in diameter with Nb of 40 vol. %. The composite rod was cold-drawn to a hexagonal shape in a cross-section with the deformation steps approximately 10-15% of reduction area. n_1 composite rods were then assembled in a Cu can. The bundled composite was evacuated, welded, extruded at a temperature below 700°C and cold drawn to a hexagonal rod. Such a procedure was repeated however, with n_1, n_2 ... n_i numbers of rods for bundling. The final product was composed of n_1, x n_2 x ... n_i of Nb/Nb-Cu fibres embedded in Cu matrix.

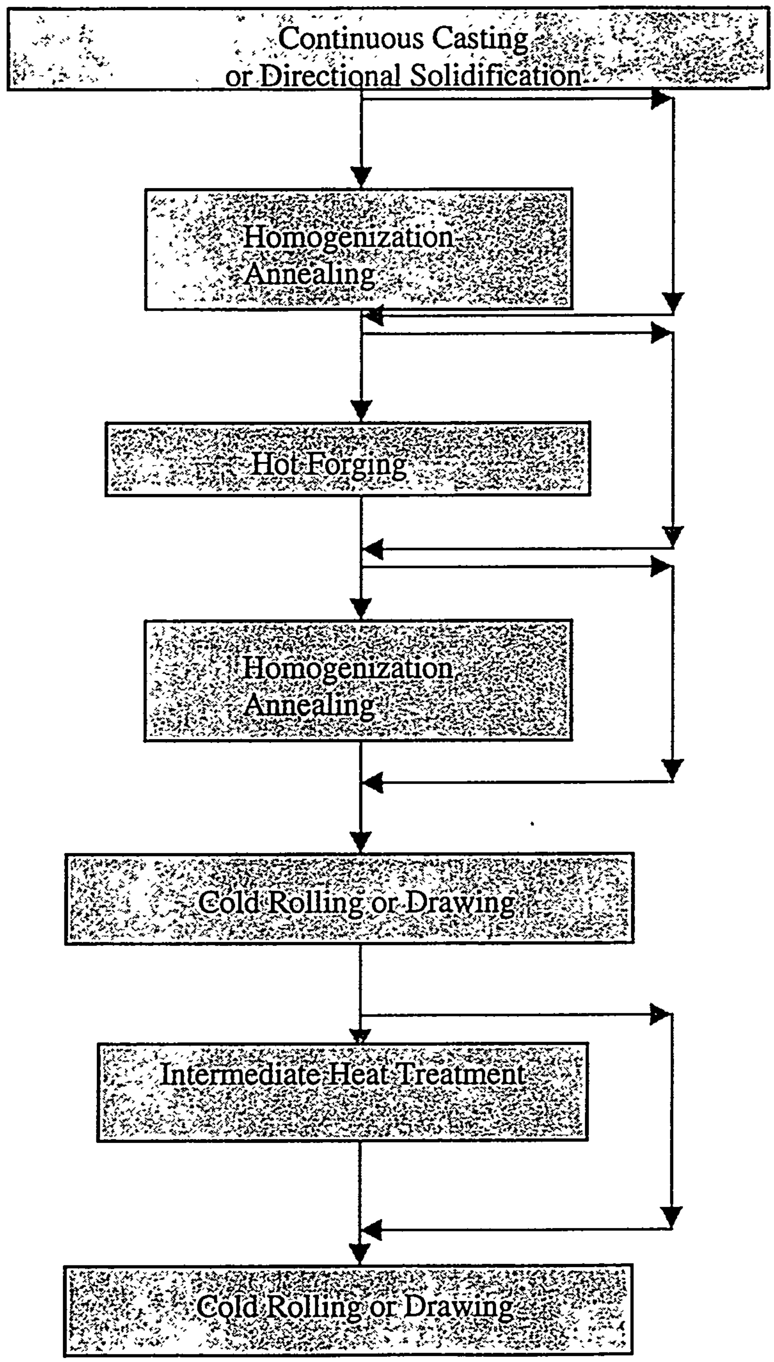

Fig. 1. Fabrication flow chart of Cu-Ag.

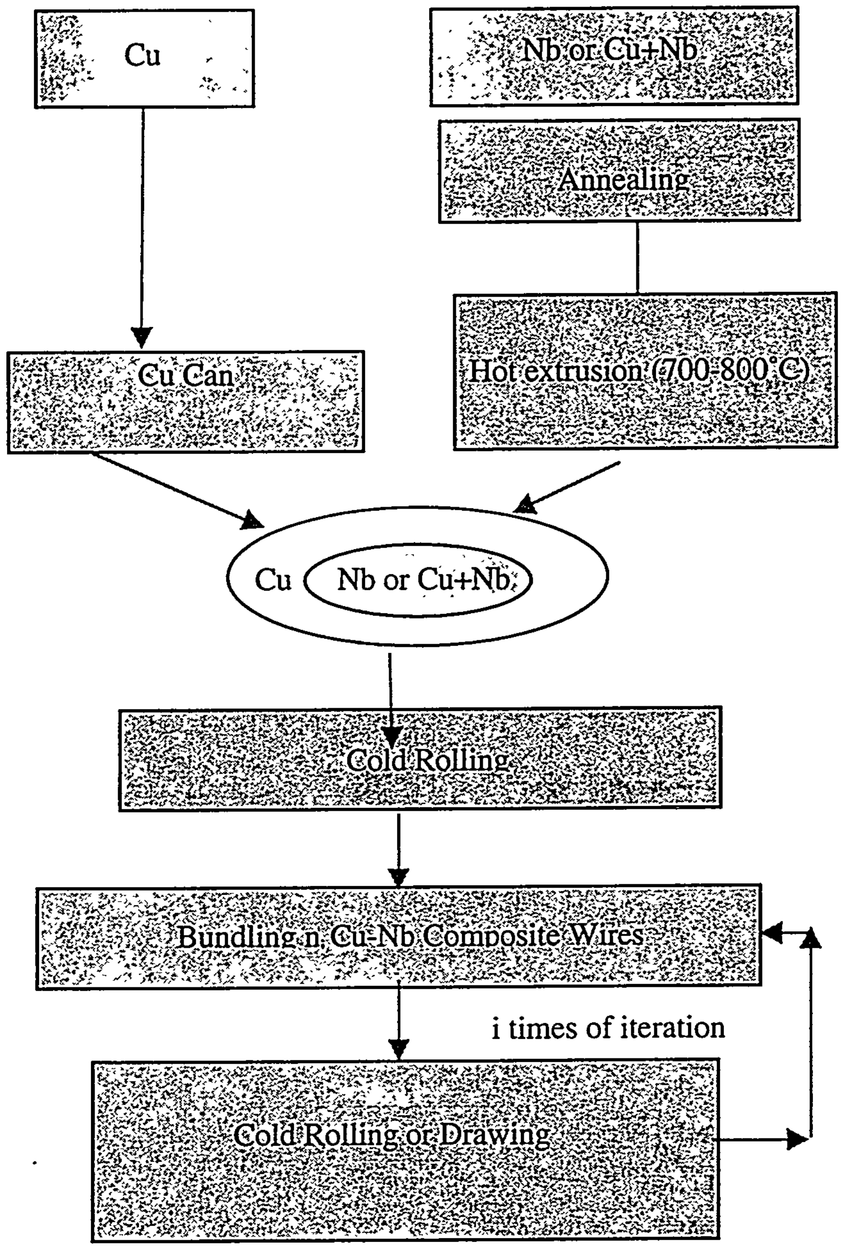

Fig. 2. Fabrication flow chart of Cu-Nb composites.

Reference:: [1] G.Frommeyer and G.Wassermann, Acta Metall, vol. 23, 1975, pp.. 1353.