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Review

Development of magnesium diboride (MgB_2) wires and magnets using in situ strand fabrication method

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Abstract

Since 2001 when magnesium diboride (MgB_2) was first reported to have a transition temperature of 39 K, conductor development has progressed to where MgB_2 superconductor wire in kilometer-long piece-lengths has been demonstrated in magnets and coils. Work has started on demonstrating MgB_2 wire in superconducting devices now that the wire is available commercially. MgB_2 superconductors and coils have the potential to be integrated in a variety of commercial applications such as magnetic resonance imaging, fault current limiters, transformers, motors, generators, adiabatic demagnetization refrigerators, magnetic separation, magnetic levitation, energy storage, and high energy physics applications. This paper discusses the progress on MgB_2 conductor and coil development in the last several years at Hyper Tech Research, Inc.

Keywords: MgB_2; LTS; HTS; Kilometer lengths; CTFF; In situ; SiC; Magnets; Coils; MRI

Contents

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1. MgB_2 wire development at Hyper Tech Research, Inc.

1.1. Strand design and manufacturing process

Hyper Tech Research, Inc., (Hyper Tech) uses a patented process for manufacturing MgB_2 superconductors; it is called the continuous tube filling and forming (CTFF) process. In the CTFF process, precursor MgB_2 powder is dispensed onto a strip of metal as it is formed into a tube. This process results in an overlap-closed tube filled with powder in continuous lengths. Fabricating precursor wire billets continuously is the fundamental advantage to the CTFF process. Hyper Tech has also used the ex situ technique (filling the tube with already-formed MgB_2 powder), but primarily uses the in situ technique for fabricating MgB_2 superconductor wire. The in situ technique involves direct CTFF filling of the "tube" with elemental magnesium and boron powder and subsequent drawing followed by heat treatment, during which the elements react to form MgB_2. The advantages of the in situ process are simplicity of fabrication, lower reaction temperatures, and increased ease in adding dopants or other additives into the wire [1]. The lower reaction temperature is particularly important as it helps to minimize the possibility of powder-barrier reactions.

The overlap-closed filled tube must be chemically compatible with the powder at the MgB_2 reaction temperature. The barrier material is typically pure niobium but Ni, Fe and Ti can alternatively be used. In general the Nb barrier is enclosed in an outer sheath, or sheaths, to aid the wire drawing and eventually to provide electrical stabilization. For most of the wire made at Hyper Tech, the overlap-closed niobium strand is inserted into a seamless copper (or copper alloy) tube and is drawn to a predetermined size, creating a monofilament MgB_2 strand. The monofilament strands are then restacked into another seamless tube; the diameter and length of this restack tube will determine the final piece length of the wire. Billets are currently being sized to produce continuous wire lengths of 5 km for a typical 0.8 mm diameter wire. Experimental work will continue to push the 0.8 mm conductor piece length up to 30 km, the usual continuously fabricated piece length for NbTi superconductor wires. The second seamless tube, or multifilament outer sheath, is typically a nickel–copper alloy such as Monel™ but it also can be copper-rich CuNi alloys. Work to develop a wire with an all copper outer tube is ongoing. The number of filaments in the restack can vary. Usually, copper stabilizer filaments are located in the center of the multifilament restacked wire.

The commercial wire currently fabricated at Hyper Tech is a multifilament strand constructed with 18 monofilaments (Nb barrier, Cu sheath) and one center copper filament restacked in Monel. The designation of this standard multifilament is "18 + 1 Nb/Cu/Monel". Fig. 1 shows a typical wire cross section.

A number of experimental strands have been fabricated for various projects. For the purpose of increasing the ductility and stability of the strand (and increasing the copper

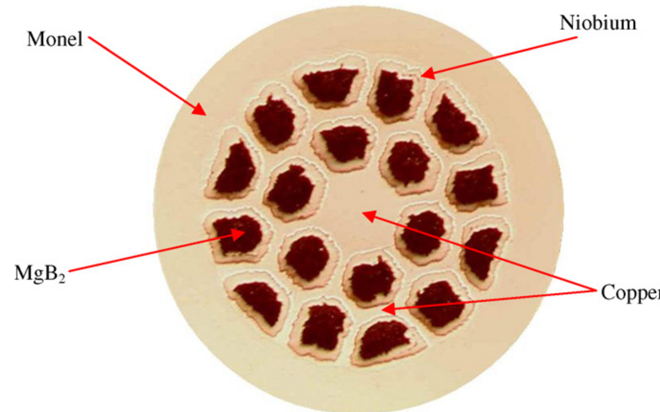

Fig. 1. Cross section of typical 18 + 1 multifilament MgB_2 wire.

to superconductor ratio), the Monel outer restack sheath is replaced with pure 101 copper or oxide-dispersion strengthened (ODS) copper, trade name Glidcop™. ODS Cu offers the benefits of lower resistivity without sacrificing a significant degree of strength needed for drawing. Strands with high filament counts and very small diameters also have been made. Hyper Tech has fabricated a Nb/Cu/Monel MgB_2 superconductor wire with up to 61 total filaments. The smallest MgB_2 superconductor strands made were a 0.07 mm round monofilament and a 0.117 mm round 7 filament Nb/Cu/Monel wire. The size of a MgB_2 filament in the case of the 0.117 mm 7 filament-restack strand was 17 μm. A MgB_2 filament in the standard 18 + 1 multifilament wire at 0.8 mm is 76 μm. Finally, experimental MgB_2 superconductor wire has been fabricated in a rectangular-shape with a 0.5×1.0 mm aspect ratio in various multifilament strand designs.

1.2. Transport current properties

Wire in short sample form, in long length on spools, or wound on coils is heat treated to react the elemental magnesium (99%) and boron (99.9%, amorphous) to form MgB_2 in the strand. Heat treatments are single-step and are performed under an argon atmosphere. The heat treatment soak temperature is normally 700 °C held for 20 to 40 min. The Ohio State University (OSU) has characterized the majority of the MgB_2 conductor manufactured by Hyper Tech [2–4]. Usually, two types of wire samples are used in transport J_cs measurements: short samples and one-meter ITER barrel coil samples. The J_c criterion for both sample types is 1 μV cm^{-1}. Four point J_c measurements are made with background fields of up to 15 T applied transversely to the strand. The ITER barrel type samples have a gauge length of 50 cm and are made with a wind-and-react protocol. ITER barrel measurements are taken at 4.2 K in liquid helium. Short samples are 3 cm in length with a gauge length of 5 mm and are measured at elevated temperatures. Fig. 2 shows typical critical current and current density measurements vs. applied field at various temperatures for the standard multifilament