DEVELOPMENT OF AN INNOVATIVE INSULATION FOR NB_3SN WIND & REACT COILS

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ABSTRACT

At the present time, Nb_3Sn is the best superconductor candidate for the realization of high field magnets (>10-11 teslas). However its implementation remains delicate because of the great brittleness of material after the heat treatment necessary to form the Nb_3Sn compounds. The conventional insulation for Nb_3Sn wind & react coils requires performing, after the heat treatment, a vacuum resin impregnation, which adds to the cost and raises failure risk. We propose a one-step innovating ceramic insulation deposited directly on the un-reacted conducting cable. The conducting cable is wound according to conventional techniques and, after the heat treatment necessary to the form the Nb_3Sn, we obtain a coil having a mechanical cohesion, while maintaining a proper conductor positioning and a suitable electric insulation. We will have studied the electric properties of superconducting cable isolated at the room temperature and at 4.2 K.

INTRODUCTION

The Nb_3Sn, which is an intermetallic compound of the A-15 family, contrary to NbTi, is very brittle and strain sensitive [1]. Nb_3Sn conductors are processed in a long (>100 h) heat treatment at about 700°C under a flow of inert gas to avoid oxidation of stabilizing copper.

In practice, for most of magnet coils, the winding is performed with un-reacted conductors and the heat treatment is applied to the whole coil to form the conductor compound. This technique is referred to as wind & react However, with this technique, the insulation of the coil becomes critical: it must be wrapped around the conductor prior to winding and must be able to sustain the high temperature treatment. Furthermore, some types of coils such, as dipoles or quadripoles, are wound from Rutherford-type cable conductor made up of Nb_3Sn multifilamentary composite strand and the geometries of both the cable and the coils force the insulation to small curvature radii.

Cable insulation is one of the most difficult issues in the manufacturing of Nb_3Sn magnets by the wind & react technique because the insulation materials must be deposited on the conducting cable before the formation of the coil and there are traditionally of organic type [2], for instance Kapton is used on the NbTi superconductors. Of course, this type of insulation does not resist to the thermal treatment at about 700°C necessary to the formation of Nb_3Sn. To overcome this drawback, various programs of R&D have explored different processes.

When the conventional insulation is applied, the cable is wrapped with a mineral fiber tape before winding and heat treatment. After heat treatment, the fragile coil is then transferred into a mold where it is vacuum-impregnated with epoxy resin. The epoxy resin enhances the turn-to-turn breakdown voltage and confers a rigid shape to the coil but the phase of vacuum impregnation increases the failure risk and is expensive.

CTD Co. in collaboration with Fermilab is developing a ceramic/organic hybrid insulation where the ceramic is wrapped onto the conductor [3]. A short curing heat treatment at about 150°C for few hours provides a rigid shape to the coil. A following heat treatment allows to form the Nb_3Sn superconductor but there is still a need for a vacuum impregnation of resin.

Florida State University and the Magnetic National High Field Laboratory have developed a sol-gel coating that provides also a ceramic insulation [4], but this coating technique requires significant extensive modification of the fabrication process.

We present the lastest results of our development regarding a technique for applying a thin pre-impregnated mineral fiber tape with a ceramic solution that exhibits both flexibility and strength to permit conductor wrapping and coil winding according to conventional insulation. During the heat treatment required for Nb_3Sn formation, the fragile coil is transforming into a rigid body, while proper conducting positioning and a good electrical insulation are maintained.

INNOVATIVE CABLE INSULATION

The wind & react technique requires that the electric insulation must be able to resist temperatures above 700°C during heat treatment of Nb_3Sn formation and to provide after a good mechanical cohesion of the coil. This is required to facilitate the assembly of the magnet and to maintain also proper conductor positioning during operation and resistance to the Lorentz's forces. Ceramic insulation provides the unique ability to resist to temperatures, and to form a solid insulating body after heat treatment. The principle of the insulation process that we have developed is based on the principles of conventional insulation. Without any change in the superconducting synthesis and shaping, whose the various stages from manufacture to wounding are clearly separated in order to facilitate the implementation.

The ceramic solution is a mixture of clays and glasses particles kept as a suspension in an aqueous phase. No organic binder is used. A 12 h stirring process is used to homogenize the solution, after which its rheological properties are characterized.

The mixture of components is adjusted to reach a rheogram such as the one presented in FIGURE 1, clays increase viscosity and glass particles must be prevented from settling. The adjustment of viscosity allows us to control the thickness of the ceramic precursor on the glass tape as well as the quality of the tape impregnation.

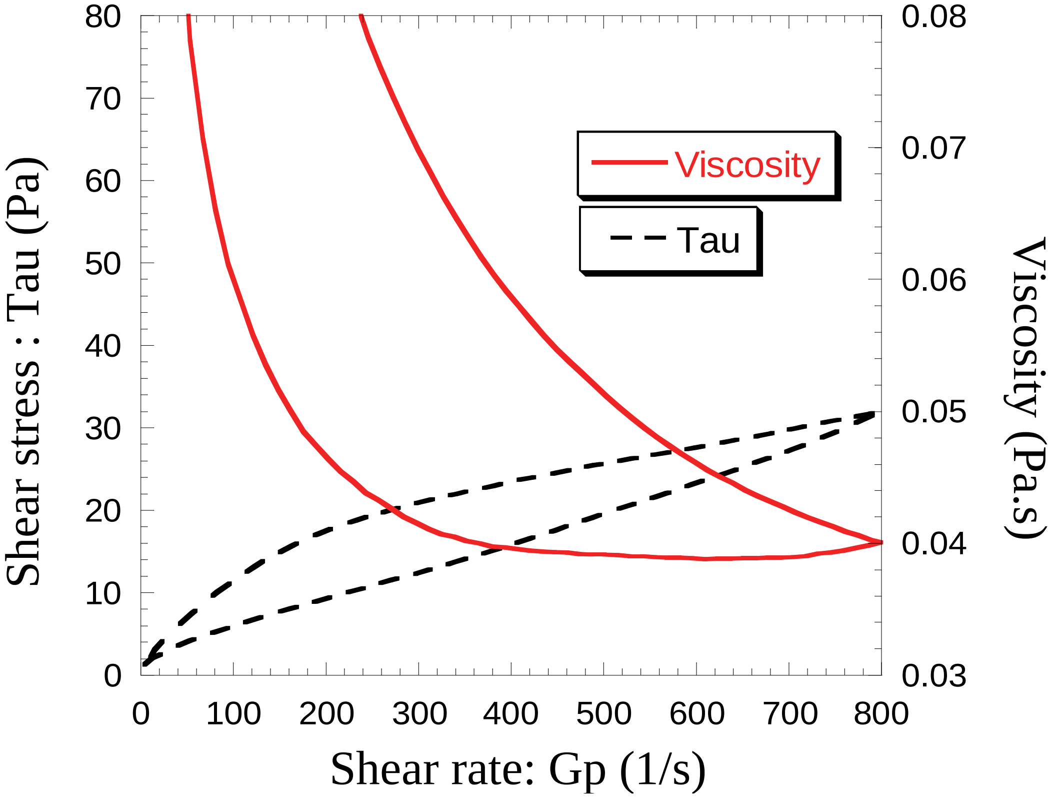

FIGURE 1. Rheological behavior of the ceramic solution of impregnation.

The solution does not contain any organic binder in order to prevent any harmful source of carbon that could hamper the electric insulation after the heat treatment. Similarly, the fiber is thermically treated prior to use to remove organic sizing.

The tape is impregnated using an impregnation facility where the mineral fiber tape is first sunk into the ceramic solution, then heated through a heating tube and finally rolled to be kept for further use. This process allowed us to prepare rollers of several tens of meters. FIGURE 2 shows the as-deposited ceramic layer possesses a good homogeneity and penetrates entirely the fibers interspace.

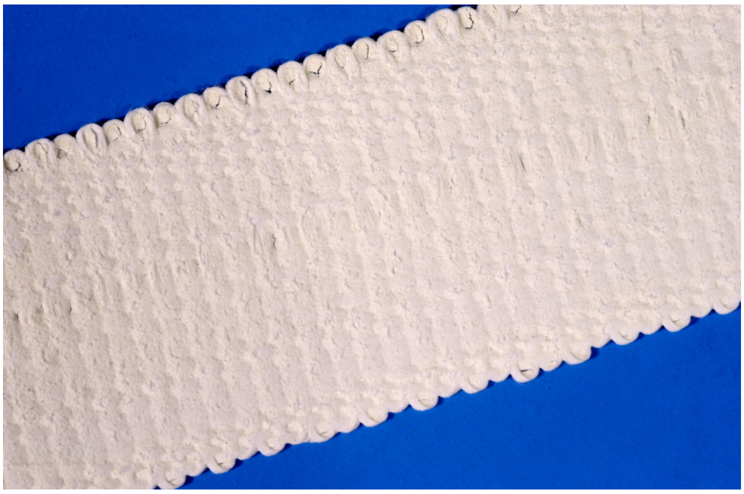

FIGURE 2. Impregnated ribbon, the ceramic penetrates entirely the fibers.

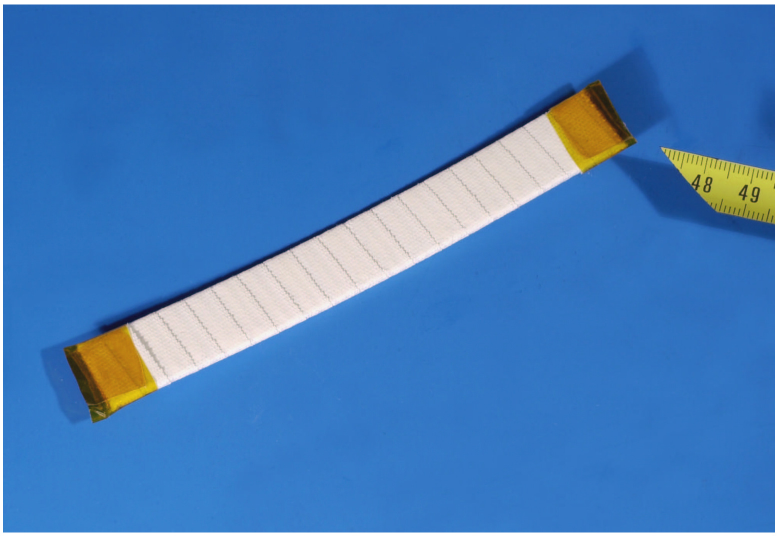

FIGURE 3. Un-reacted Rutherford cable is wrapped by the pre-impregnated ribbon.

According to the technique of conventional insulation, the pre-impregnated is wrapped around the un-reacted conductor cable presents in FIGURE 3. The plastic properties of clay make it possible to bend the impregnated ribbon without any exfoliation or deterioration of the layer which as illustrated in FIGURE 4. The winding coil is then thermically processed according to the cycle of formation of Nb_3Sn. During this phase, the melting of the glass at low temperature brings mechanical rigidity to the coil by bringing cohesion between the spires. FIGURE 5 presents a stack of insulated Rutherford-type cable conductor obtained following this process after heat treatment. The first qualitative results are encouraging: on this stack a good cohesion between the conducting wrapped cables insulated has been observed. The next step will be the mechanical characterization of insulation.

FIGURE 4. Bending test on un-reacted Nb_3Sn cable wrapped with impregnated ribbon.

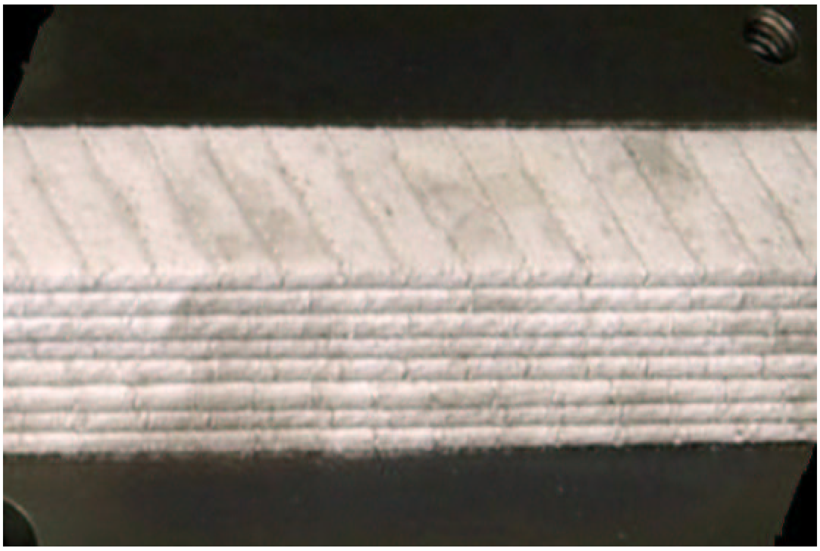

FIGURE 5. Stack of Nb_3Sn cables insulated after heat treatment, wich present a good cohesion.

ELECTRICAL CHARACTERISATIONS

Various electrical measurements make it possible to determine the characteristics of the innovating insulation.

A. Dielectric Strength

Measurements are taken on a dense ceramics sample prepared with a mixture of powder equivalent to the dry matter used for the solution of impregnation. A light pressing of the powder forms a sample in the shape of disc then a thermal treatment at 660°C makes allow to make denser the sample. The dielectric strength at 4.2 K under He gives a value superior to 75 kV/mm who corresponds to the order of magnitude of the traditional insulations with vacuum-impregnated of epoxy resin [3].

B. RRR Measurements

The value of RRR (1) is used to check that ceramics insulation does not deteriorate the properties of conduction of stabilizing copper of the Nb_3Sn wires during the thermal cycle. Measurements are taken on conducting Nb_3Sn wires in a cryostat, the temperature is gone down to 4.2 K under He then the cryostat is heated slowly by a resistance, measurements points of the resistivity are carried out regularly, RRR value is defined by:

$$\mathrm{RRR} = \frac{\text{Resistivity at 298 K}}{\text{Resistivity at transition temperature}} \qquad (1)$$

The current is limited to 0.5 A to avoid a heating of the conductor on the level of the electrical contacts. For problems of dimension, the Nb_3Sn wire cannot be wrapped by the pre-impregnated mineral fiber tape, the sample shows in FIGURE 6, consists of a wire covered with ceramic solution, the unit having undergoes the thermal cycle. The RRR value is similar between a covered wire with ceramics and a bare wire.

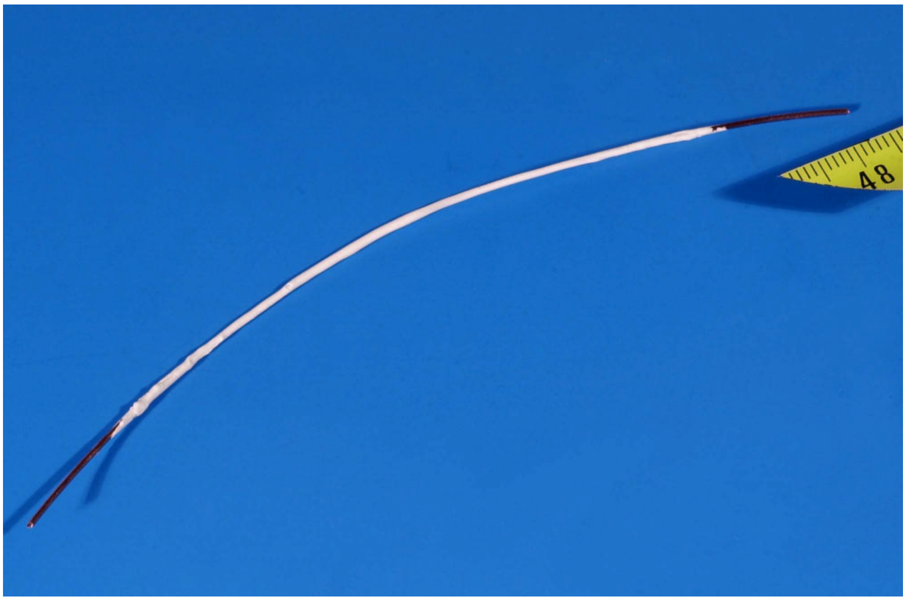

FIGURE 6. Nb_3Sn wire covered with ceramic solution for RRR measurement.

The FIGURE 7 shows no harmful interaction appears between ceramics and stabilizing copper during the lengthy heat treatment.

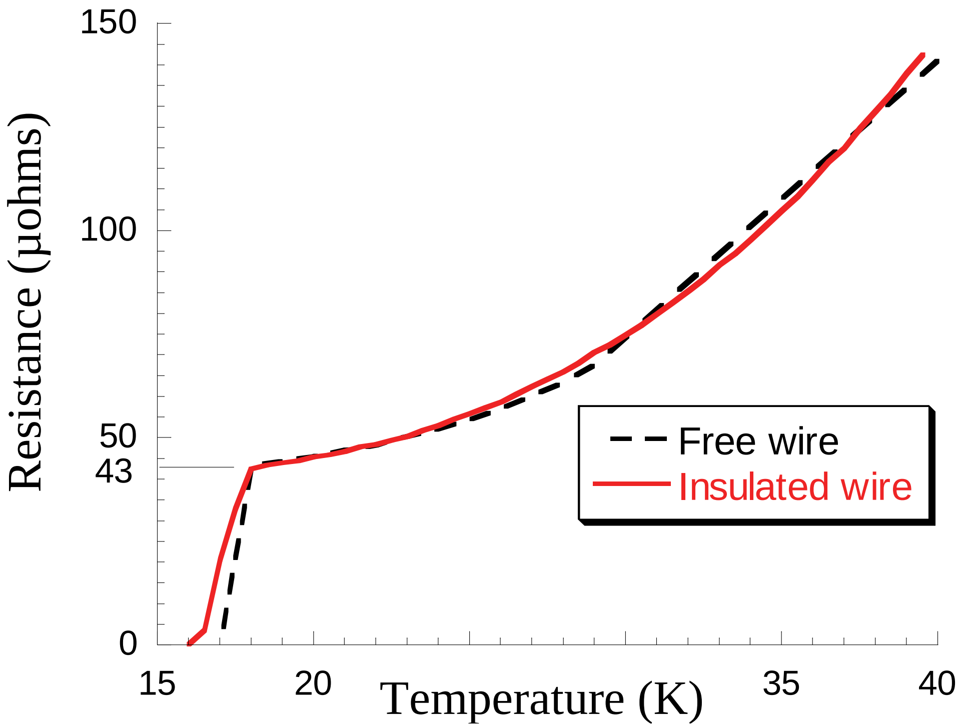

FIGURE 7. Comparison of RRR measurement between an insulated wire and non-insulated, resistance to 298 K is identical for the two wires.

FIGURE 8. Vamas coil for Jc measurement; the pre-impregnated tape wraps the cylinder.

C. Critical Current

Measurements are taken in a Teslatron 17 T, Nb_3Sn wire is wound in a grooved cylinder and a graphite lubricant is sprayed on the cylinder holder prior to winding the sample in order to avoid sticking during the heat treatment of Nb_3Sn. To test the insulation, the cylinder is wrapped by the pre-impregnated mineral fiber tape then to wound by the conductor wire to manufacture the coil test, which, as illustrated in FIGURE 8. A comparison of current critical between a wrapped sample and not wrapped will make it possible to check if the insulation have a significant effect on the critical current of Nb_3Sn conductor.

CONCLUSION

We have shown the feasibility of this innovative insulation with superconductor magnet system. The ceramique gives a cohesion to the coil after the heat treatment and no harmful reaction modifies the electrical properties of Nb_3Sn conductor. A series of mechanical test will make it possible to precise the properties of the ceramic insulation.

This method of insulation using a ribbon impregnated by a ceramic solution make it possible to keep the traditional technique of W&R Nb_3Sn coil, it allows to avoid an important cost of implementation.

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