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Research of mechanical and void properties of composite insulation for superconducting busbar

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HIGHLIGHTS

- Two curing methods for the pre-preg on the superconducting busbar are researched.
- Vaccum bag and silicone rubber is used for pre-preg curing as complement of VPI in fusion filed.
- The results of mechanical properties and void content is described and discussed.

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ABSTRACT

Pre-preg material has been widely-used in the industry of the aerospace, the wind power, which has many advantages on manufacture process, and can be chosen as an effective complementary insulation method for the Wet-winding and Vacuum Pressure Impregnation technology in the field of superconducting fusion magnets. ASIPP undertaken many engineering tasks on the superconducting coil and busbar design and manufacture for the large fusion device, the pre-preg material and the relevant curing technology were researched as a new method for the high voltage potential components in ITER Feeders, such as the busbars and current leads. Two types of Chinese industrial glass fiber pre-preg insulation composite material were studied and pre-qualified using vacuum bag and silicone rubber assistance technique in ASIPP. The mechanical properties including the ILSS and UTS at 77 K, and void content of this composites were measured and discussed in this paper in detail.

1. Introduction

The common and conventional insulating strategy for the large scale superconducting magnet is the Vacuum Pressure Impregnation (VPI) technology. In the VPI process, the liquid resin is pumped and compressed into a solid mould. The superconducting coil wrapped with the dry glass fiber textile is pre-installed in the mould, and impregnated and cured by the resin. The main benefit of the VPI technology is immensely eliminating the void content in the insulation system. The limitation of the micro void can improve the mechanical properties and the lamination bounding quality of insulation layers. So the VPI technology is widely-used for the large superconducting coil insulation manufacture in the nuclear fusion field [1,2].

Though the insulation manufacturing process for the superconducting coil has the VPI technology as the reasonable and satisfactory solution, the insulation method for the single superconducting cable (Cable-In-Conduit-Cable, so called busbar) in Feeder system of the fusion device and reactor is still worth further study [3]. In the Feeder system, the current is transported from the power plant to the coil termination via the superconducting busbars. Normally, due to the purpose of the simplicity of construction and on-site assembly, the whole Feeder is segmented into many sub-components, for instance, the Feeder of ITER (International Thermonuclear Experimental Reactor) consists of Coil-Terminal-Box and S-Bend-Box (CTBSBB), Cryostat-Feed-Through (CFT), and In-Cryostat-Feeder (ICF) [4]. The busbars in different sub-components are irregularly shaped, as shown in Fig. 1. The length of the sectional busbar is often several dozen meters and

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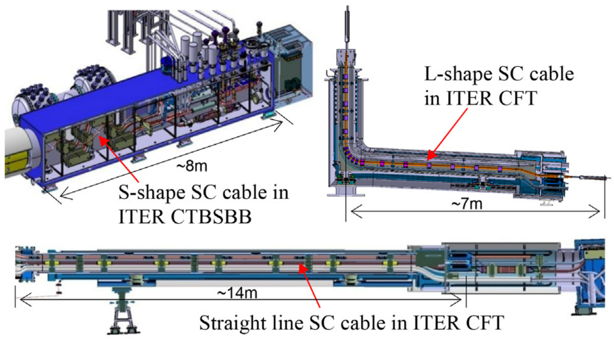

Fig. 1. Different shaped superconducting cables in ITER Feeder system.

with the diameter of twenty to forty millimeters [5]. The complicated configuration makes it difficult and expensive to build up the VPI mould for each busbar, so the traditional insulation scheme for Feeder busbar is "wet-winding" technology, which is simple for the implement, but hard for the quality control [6]. In order to avoid potential failure and reduce the operational risks, the "pre-preg" technology becomes an alternative solution for the long length single busbar insulation in the superconducting magnet accessories. The pre-preg material is the pre-impregnated glass fiber textile with epoxy resin matrix, it can be easily cut into tapes for insulation wrapping onto the busbar surface. In ITER Central Solenoid (CS) model coil fabrication, the pre-preg material and processing was used for the coil turn insulation [7]. The pre-preg technology was also applied in K-STAR (Korea Superconducting Tokamak Advanced Research) Feeder system [8]. The prior successful engineering application of the pre-preg for the superconducting busbar provides beneficial reference for the ITER Feeder system insulation qualification. But because of the withstanding voltage of ITER magnet insulation system exceeding 30 kV, the insulation structure of ITER Feeder busbar is designed to pre-preg tape and Kapton tape compounding (GK) wrapping structure, which is the up-to-date design from previous one, and needs the systematical experimental verification.

ASIPP (Institute of Plasma Physics, Chines Academy of Science) is undertaking the tasks for ITER Feeder insulation manufacture. In recent work, the pre-preg technology and the candidate pre-preg material has been researched and improved. This paper introduces the test results of mechanical properties and void content of two types Chinese industrial pre-preg materials, this activities presented in the paper are preliminary R&D before the formal ITER material qualification.

2. Raw material and insulation structure

2.1. Materials

SW210-LTC80 and RW210-LTC80 glass fiber pre-preg from *AVIC* Composite Company are chosen for the preliminary R&D of ITER Feeder busbar insulation. The thickness of the pre-pregs is 0.2 mm, and the width is 25 mm. The resin content is 40% (on weight basis), the resin system is low temperature curing matrix, and curing temperature is 80 °C for 12 h. The resin in the matrix is DGEBA epoxy, and the hardener is DCD. The shelf life of the material is more than 300 days at −18 °C, and 30 days at room temperature.

The main differences of these two pre-pregs are the glass fiber type. The glass fiber in SW210-LTC80 is HS2, and in RW210-LTC80 is R, where the HS2 and R glass fiber are the commercial brand name. Table 1 shows the chemical composition of the glass fibers. Table 2 shows the main properties of the glass fiber.

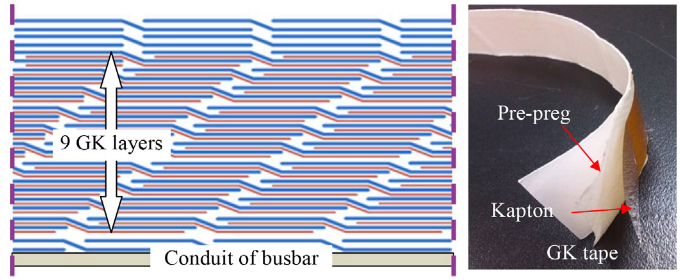

Fig. 2. Left sketch is the insulation structure of ITER Feeder busbar; right picture shows the compounding GK tape.

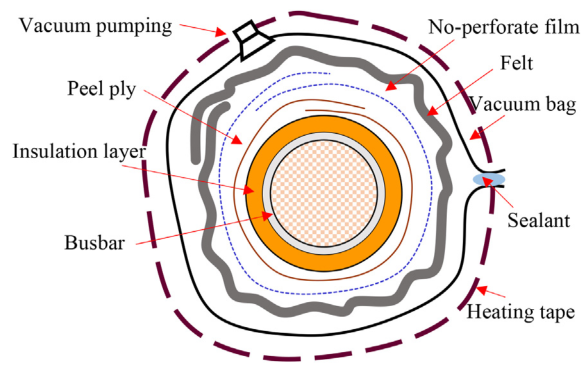

Fig. 3. The cross section sketch of vacuum bag curing technology setup for the superconducting busbar.

The Kapton-HN film from *DuPont* Company is applied in the insulation structure, the thickness of Kapton tape is 0.05 mm, and the width is 21 mm. The Kapton tape has relevant high dielectric strength and excellent cryogenic stability, which is an effective barrier for the defect generation and propagation, finally increasing the high voltage margin of the insulation system. The Kapton tape is compounding with the pre-preg tape to form the GK tape, as shown in Fig. 2, which as the main material is wrapped onto the superconducting busbar.

2.2. Insulation structure of ITER feeder busbar

The detailed insulation layout of ITER Feeder busbar is shown in Fig. 2. One layer of 0.2 mm pure pre-preg tape with 50% overlapped plus nine layers of 0.25 mm GK tapes with 50% overlapped, and finally plus two layer of 0.2 mm pre-preg tape with 50% overlapped. The theoretical thickness of the insulation layer is 5.7 mm.

3. Pre-Preg curing method

In normal curing process of pre-preg material, multi-layers of pre-preg are overlaid onto the mandrel to the defined final geometry. Then the whole work piece is sealed into the vacuum bag, and fully consolidated in the autoclave, which can provide more than 0.5 MPa uniform compaction force on the pre-preg during the curing processing [9,10]. But limited by the dimension of the ITER Feeder busbar, it is almost impossible to find an autoclave with suitable volume to hold all types of busbars. Two improved pre-preg curing processing was developed and verified for ITER Feeder busbar, namely "Vacuum bag" curing technology and "Silicone rubber compression" curing technology.

As shown in Fig. 3, in the vacuum bag curing technology without autoclave, the insulation tapes are wound on the busbar to the required structure and thickness. The peel ply, the no-perforated film, and the felt are installed successively. Then the busbar with