§14. Mitigation of Critical Current Degradation in Mechanically Loaded Nb_3Sn Superconducting Multi-strand Cable by Ice-molding

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We surveyed the technique to mitigate critical current degradation in mechanically loaded Nb_3Sn superconducting multi-strand cable. It was reported that Lorentz force caused degradation of critical current in the ITER-TFMC conductor [1, 2]. We employed our innovated novel critical current and stability experimental setup utilizing a closed electric circuit with a superconducting cable to investigate this phenomenon. The feature of this setup is mechanical loading implied to the multi-strand cable in the transverse direction. As experimental results without any counterpart, we have observed significant degradation due to compressive stress of 30 MPa. This degradation was found irreversible, when it was unloaded. We tested the cable molded with epoxy or ice, too. No degradation occurred with these counterparts. We also tested the cable with smaller void fraction, which is the sample of heavily compressed before heat treatment. The small void fraction is expected to result in small degradation.

Our test was based on electro-magnetic induction by a bias superconducting magnet. By using the induction current, the test process can be made simple and safe.The circuit is closed and circuit current, *I*, is induced by magnetic flux change, $d\phi/dt$. The voltage of $d\phi/dt$ is constant during the change rate in magnetic field is constant, and is balanced with sum of induction voltage of closed circuit, $L(dI/dt)$, joint voltage, $R_J I$, and superconducting cable voltage, $R_{SC} I$ as showin in Eq. 1.

$$\frac{d\phi}{dt} = L\frac{dI}{dt} + R_J I + R_{SC}(I, B, T, \varepsilon)\, I \qquad (1)$$

Here, R_J is electric resistance of the cable joint. R_{SC} is electric resistance of the superconducting cable. Since R_{SC} is given by *V-I* property of the superconducting cable, it is a function of current, *I*, magnetic field, *B*, temperature, *T*, and strain, ε. *I* is regulated by both R_J and R_{SC}, basically. However, at high field, R_{SC} is dominant because that decrease of $R_J I$ due to smaller critical current. Consequently, we obtain regulated current, i.e. critical current, by R_{SC} with this experimental principle.

A fabricated sample is shown in Fig. 1. 18+9 Cu multi-strand Nb_3Sn cable was tested. The bias magnetic field was applied in the vertical direction in Fig. 1 and compressed portion located at the centre of the bias magnetic field. The closed circuit of the cable was made on a round shape stainless mandrel and both ends were soldered. Near the joint, a hall element was attached to measure the circuit current, and a heater was installed to break the persistent current. Three extensometers were installed to measure the deformation of compressed portion.

The test was carried out using 18 T superconducting magnet at Tohoku Univ. The ramp rate of bias field was 0.58 T/min. The load was applied by a motor and gear system. The compressive load was applied up to 2770 kgf. Here, 2000 kgf corresponds to averaged stress of 30 MPa on the compressive plane. After the load reached at the related compressive load, the gear was stopped and the bias magnetic field was ramped up and down. Results of the critical current measurement for ice –molded sample is shown in Fig. 2 a). No degradation due to compressive load was observed. In contrast, in unfrozen case, the degradation observed as usual cable samples. In Fig. 3, degradations in various samples are summarized. It was revealed that the media in-between strands is effective to mitigate the degradation up to 30 MPa in compressive stress.

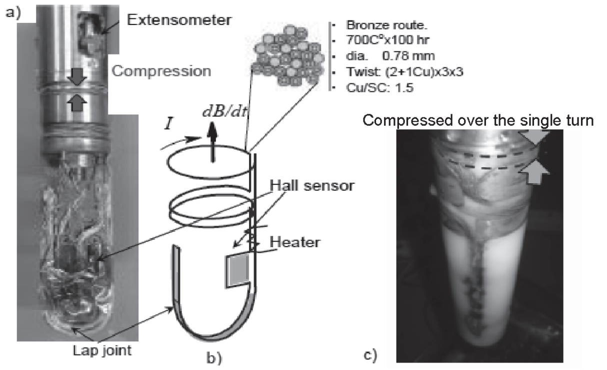

Fig. 1 Configuration of the sample and c) ice-molded cable.

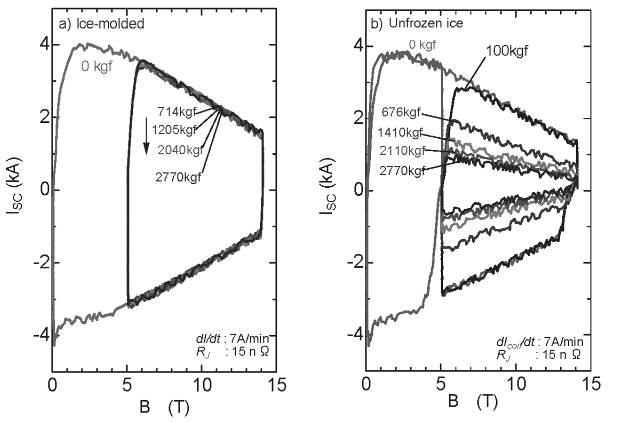

Fig. 2 Magnetic field dependences of critical current. The parameter is transverse load. a) ice-molded and b) unfrozen.

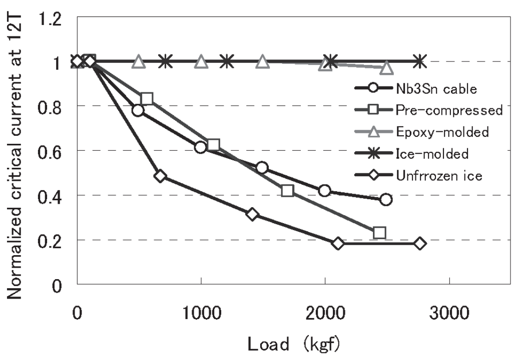

Fig. 3 Degradation of critical current due to mechanical load.

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Reference

1) Mitchell, N., Cryogenics**43** (2003) 255.
2) Ulbricht, A. *et al*., FED **73** (2005) 189.