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Introduction and results of the Bonding Experiments (BOX).

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Abstract

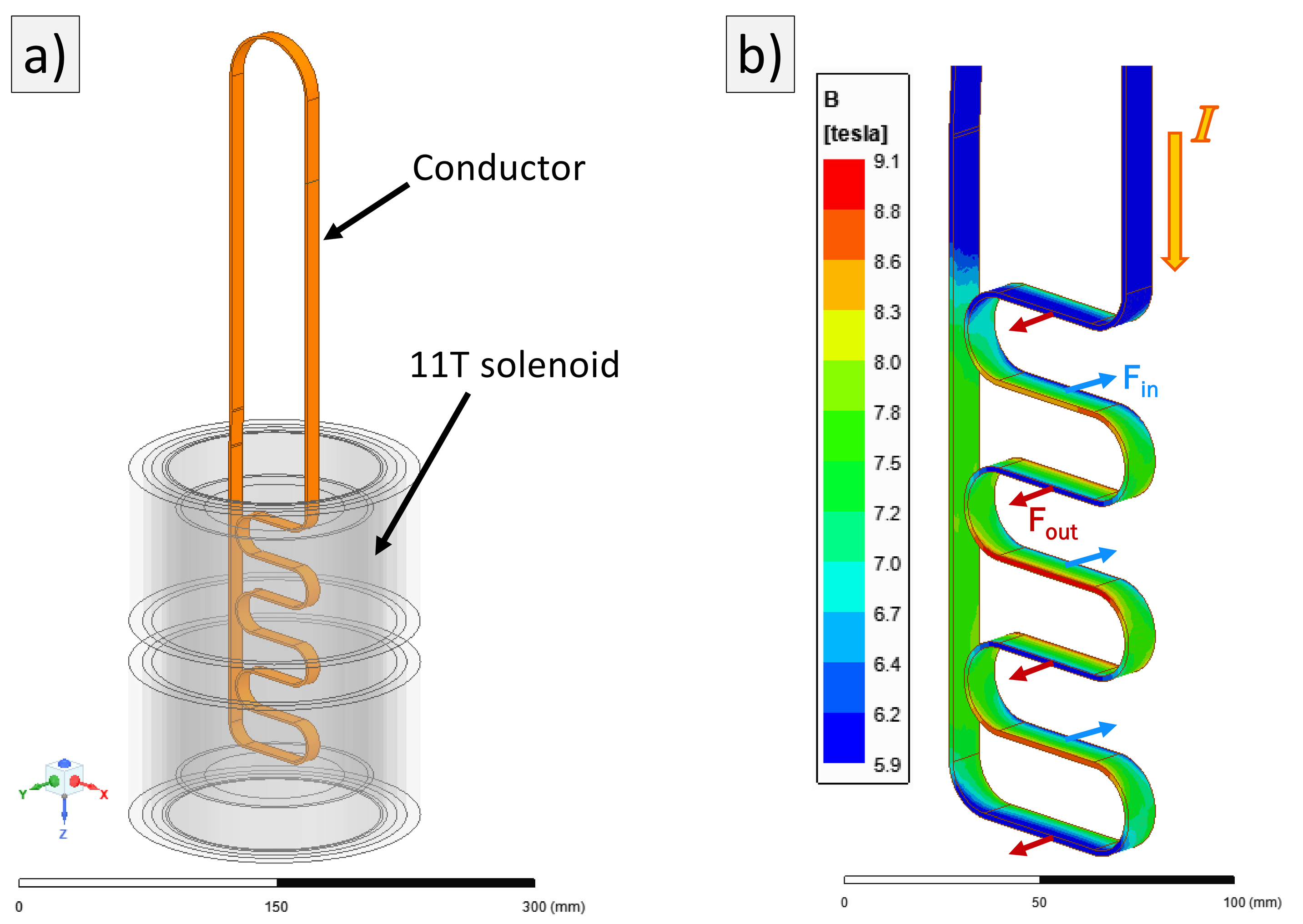
BOnding eXperiments (BOX) are a novel, affordable and fast benchmarking solution aiming to reproduce specific mechanisms of training and performance limitations in Nb_3Sn and Nb-Ti superconducting magnets. The BOX samples are tested at the University of Twente at 4.2 K within a solenoidal background field with sufficiently high magnetic forces. Following conventional manufacturing processes, the fully instrumented BOX samples have been shown to exhibit training and memory behaviour similar to their respective full-scale magnets. Improvements to the fabrication of the BOX samples have successfully reduced training and more unconventional impregnation systems such as paraffin wax have reached the estimated I_c with no training quenches at all. In this contribution we will introduce the BOX sample experiment and first test results.

Introduction

High-field Nb_3Sn accelerator type magnets are frequently subject to lengthy magnet training [1]. The training is partially due to the failure of the electrical insulator and encapsulating resin materials and their interaction with the cable and coil structural elements [2], [3]. Furthermore, the resin also functions as a glue that binds the cable-glass-resin composite to structural coil components, such as wedges, spacers, central poles, or winding formers. With sufficient stress from Lorentz forces and thermal contraction mismatch between the coil materials during cool down to 4.2 K, the bond between interfaces may fail resulting in de-bonding, movement and cracking leading to magnet quenches and long training.

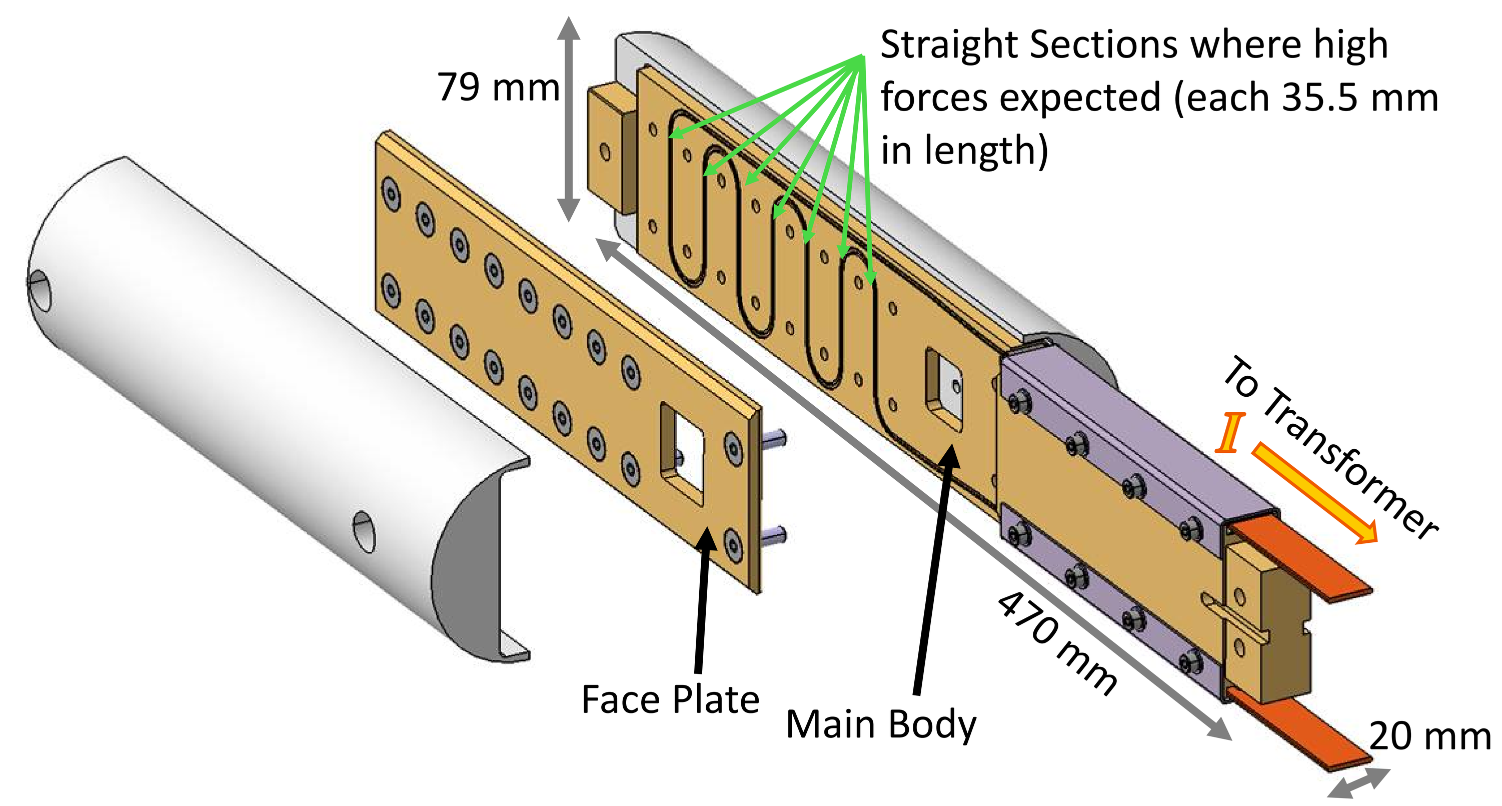
Assessing materials and improving fabrication techniques for reducing training in high-field Nb_3Sn magnets are prohibitive in terms of cost and time especially when wanting to obtain representative behaviour at 4.2 K within high magnetic fields.

The bonding experiment (BOX) samples, further detailed in [4], provide a cost-effective and quick turnaround experiment for assessing different materials and fabrication techniques within a high solenoidal magnetic field (7.5 T) at 4.2K. Remarkably, only slightly more than 1.2 meters of Nb_3Sn conductor is required.



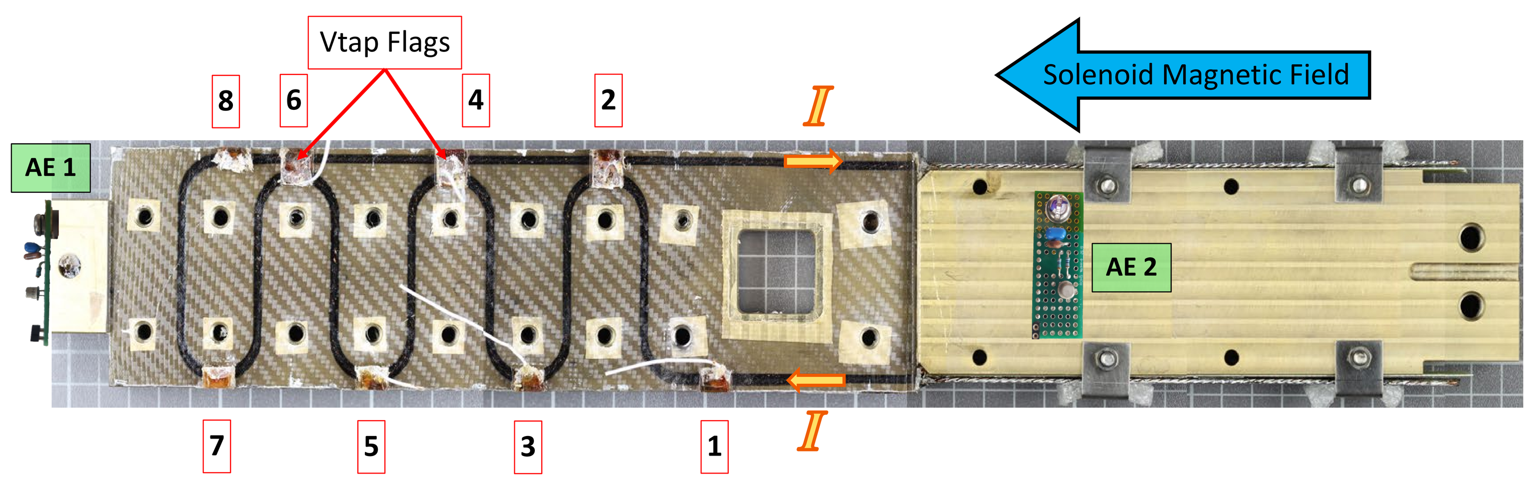
a) Samples are placed within the 11 T Solenoid (typically operating at 7.5 T) at the University of Twente [5] in liquid helium at 4.2 K and powered at 200 A/s.

b) The central straight sections of the serpentine cable are within the 140 mm high field region and are most likely to fail owed to higher (<10 MPa) shear stresses.



BOX Sample Overview

The BOX sample consists of a conductor following a serpentine channel within a main body. A faceplate is screwed unto the main body to contain the Lorentz forces generated during the powering of the conductor. Depending on the current direction, some straight sections will either be pushed into the channel (F_{in}) or pulled out of the channel (F_{out}) producing shear stresses on the wall interface.



Sample preparation

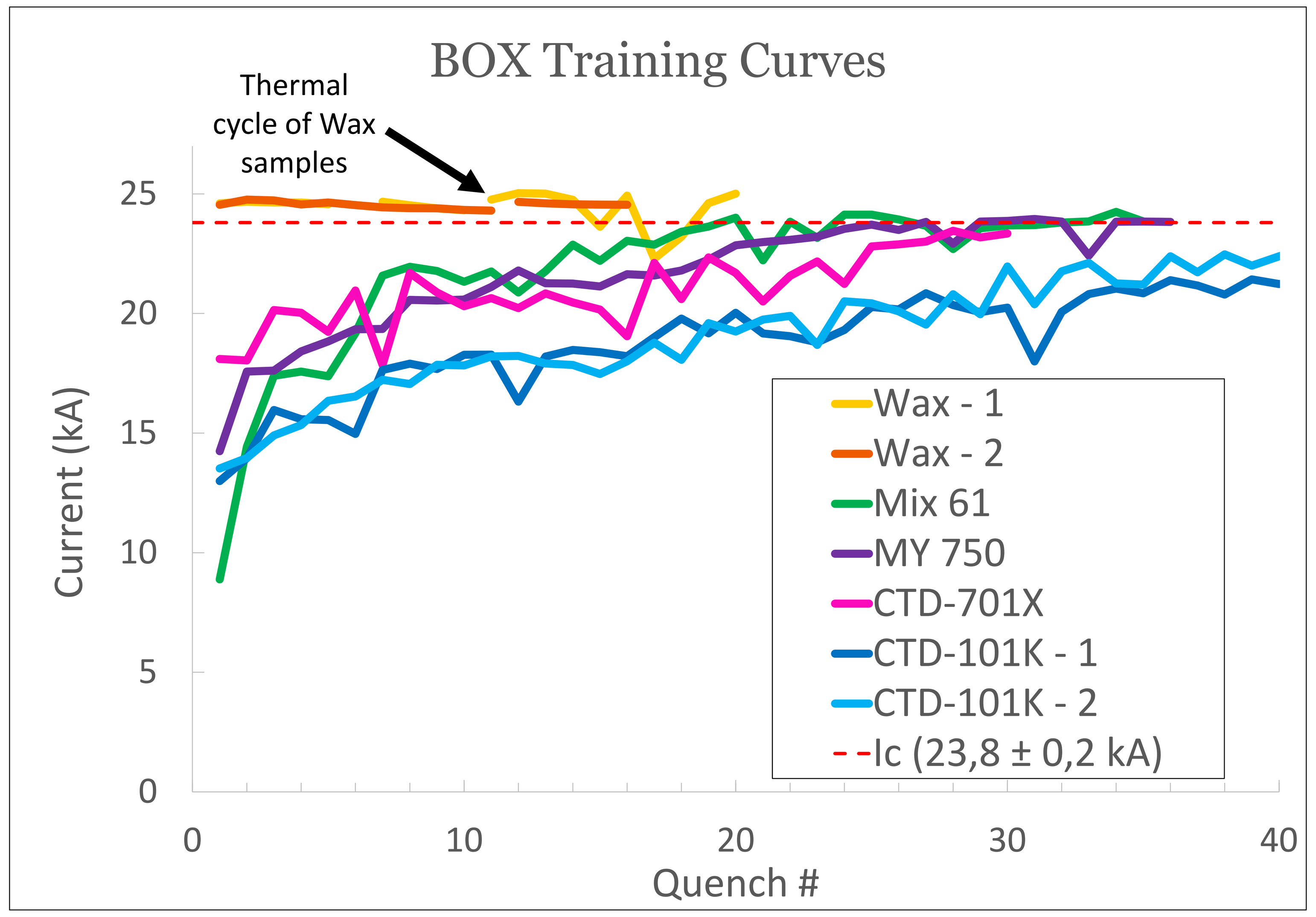
The BOX samples are wound using specific tooling and follow the recommended heat treatment plateaus for the Nb_3Sn conductor up to 665°C. The samples are then impregnated at approx. 1-3 mbar in an open-top vessel within a large vacuum vessel. The curing of the samples is performed in a separate oven within atmospheric pressure and at the required temperature for the curing of the resin. Once impregnated, the samples are instrumented with acoustic sensors (AE) [6] and voltage taps (Vtap).

Three samples were impregnated with Mix 61 [7] resin with varying improvements in fabrication with the best performing sample, shown here, used sandblasted channels, no mica in the insulation and best efforts made to wash off the sizing on the fibreglass braid prior to winding. These enhancements made a lasting improvement on the training behaviour of Mix 61 samples.

Therefore, the same fabrication process was used for producing samples impregnated with MY 750 [7], CTD-101K [7], CTD-701X [8]. In addition, two samples were impregnated with paraffin wax (POLARIT® G 54/56). The training curves for these BOX samples are shown below.

Experimental Results

All samples were powered until they quenched and allowed to train. The wax samples did not train and showed consistent behaviour. All resin impregnated samples exhibited typical training curves with extensive training.



Concluding remarks:

- BOX samples produce representative training behaviour seen in high-field magnets and can be used to asses materials and fabrication processes.
- Paraffin wax samples showed no training, reached beyond I_c and had good memory when warmed up to room temperature.
- All resin BOX samples tested in this configuration until now exhibit long training compared to wax impregnated samples.

References

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