

ABSTRACT

High temperature superconductor (HTS) devices often need conductors with transport capacity obtained by combining more REBCO (RE = rare earth, B = barium, C = copper, O = oxygen) coated conductors (CC) tapes in parallel, forming a cable. One method of cabling flat REBCO CC tapes is the Tape On Round Tube (TORT) concept. In TORT cables, multiple coated conductors are wound in a helical fashion on a copper tube, through which the coolant (liquid nitrogen or cold helium vapour) may flow. The performance of HTS tapes is affected by mechanical stresses arising during cable production, which can cause their permanent degradation, because of cracks in the superconducting layer. A detailed structural finite-element (FE) analysis using the program code ANSYS was carried out to investigate the stress-strain behaviour of CC tapes under tension and bending loading during the winding process. In addition to the finite element method (FEM) investigations, the measurements of critical current dependence on the axial and bending load of REBCO CC tapes at room temperature were performed. Finally, the possibility of the application of FEM simulation to predict the critical loads of REBCO CC tapes subjected to mechanical loading during the winding process is assessed.

INTRODUCTION

The REBCO CC tapes have appropriate mechanical properties as well as high-current and high-field capabilities. Because of these characteristics, they are expected to be suitable for some applications, that require high current densities, such as for high field magnet applications [1]–[3]. However, these applications require multiple REBCO tapes to be assembled into suitable geometries to provide high current densities. Few cabling methods for HTS tapes have been developed, e. g. Roebel Assembled Coated Conductors (RACC) [4], Twisted Stacked-Tape Cables (TSTC) [1] and Conductor on Round Core cables (CORT) [5]. From the cable production point of view, the CC tapes used in such coil applications can experience several forms of stresses, such as bending stress, radial stresses - both transverse compressive and tensile stress (normal to the surface). The REBCO tapes can be subjected to several forms of stresses, according to the cabling method, in this work we investigated dependence of strain on various winding angles and tension forces. Such stress state is the consequence of new cabling method, Tapes On Round Tube (TORT). It is a novel concept of superconducting cable, where multiple coated conductors are wound in a helical fashion on a copper tube, through which the coolant (liquid nitrogen or cold helium vapour) flows. This paper presents the results of FE analysis of the 3D strain behaviour of the REBCO tapes during winding process. All FE analysis and experiments were performed at room temperature (RT). ANSYS R18.1 Academic Workbench environment was used for this modelling task. In addition to the FE analysis, REBCO CC tapes wound in a helical fashion on tube of 6.35 mm in outer diameter under various winding angles and tensile forces were prepared and electrical measurements were performed.

REFERENCES

- [1] N. C. Allen et al. *IEEE Trans. Appl. Supercond.*, vol. 25, no. 3, pp. 1–5, Jun. 2015.
- [2] D. C. van der Laan. *Supercond. Sci. Technol.*, vol. 22, no. 6, p. 065013, 2009.
- [3] G. De Marzi et al. *IEEE Trans. Appl. Supercond.*, vol. 26, no. 4, pp. 1–7, Jun. 2016.
- [4] W. Goldacker et al. *IEEE Trans. Appl. Supercond.*, vol. 17, no. 2, pp. 3398–3401, Jun. 2007.
- [5] D. C. van der Laan et al. *Supercond. Sci. Technol.*, vol. 28, no. 12, p. 124001, 2015.
- [6] K. Ilin et al. *Supercond. Sci. Technol.*, vol. 28, no. 5, p. 055006, May 2015

ACKNOWLEDGMENT

This work was supported in part by the Grant Agency of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences (VEGA) under contract No. 1/0151/17, by the Slovak Research and Development Agency (APVV) under contract No. APVV-14-0438, and by the project “Study of the TORT cable concept based on a high temperature superconductor” under contract No. 1379, and is the result of the project implementation: CE for development and application of advanced diagnostic methods in processing of metallic and non-metallic materials - APRODIMET, ITMS: 26220120048, supported by the Research & Development Operational Programme funded by the ERDF.

CONTACT

Slovak University of Technology
in Bratislava
Faculty of Materials Science and Technology in Trnava
Address: Jana Bottu 25, 917 24 Trnava, Slovakia
email: eva.michalcova@stuba.sk
web: www.mtf.stuba.sk

Structural modelling of REBCO coated conductor tapes in TORT cables

Eva Michalcová, Mária Behúlová, Michal Vojenčiak, Ľubomír Frolek, Michal Skarba, Marcela Pekarčíková, Marián Drienovský, Fedor Gömöry

EXPERIMENTAL

A. Uni-axial tension of REBCO CC tape

Several samples of SuperPower tapes were subjected

to the tension loading in order to determine the mechanical axial tensile stress-strain characteristics. Specifications of the studied REBCO CC tapes are given in Tab.1. The obtained stress-strain data served as an input for numerical tape modelling. The elongation of the tape sample was measured by a pair of extensometers (double extensometer configuration), which were placed in the centre of the sample and clamped with two springs. The gauge length was 20 mm. The signals from the extensometers are recorded separately and then averaged. The displacement speed is set to 6 mm/min and the strain rate was about $4.1 \times 10^{-4} \text{ s}^{-1}$. All measurements were performed at RT. The results of the uni-axial tension test are shown in Fig. 1 as plotted stress-strain curve.

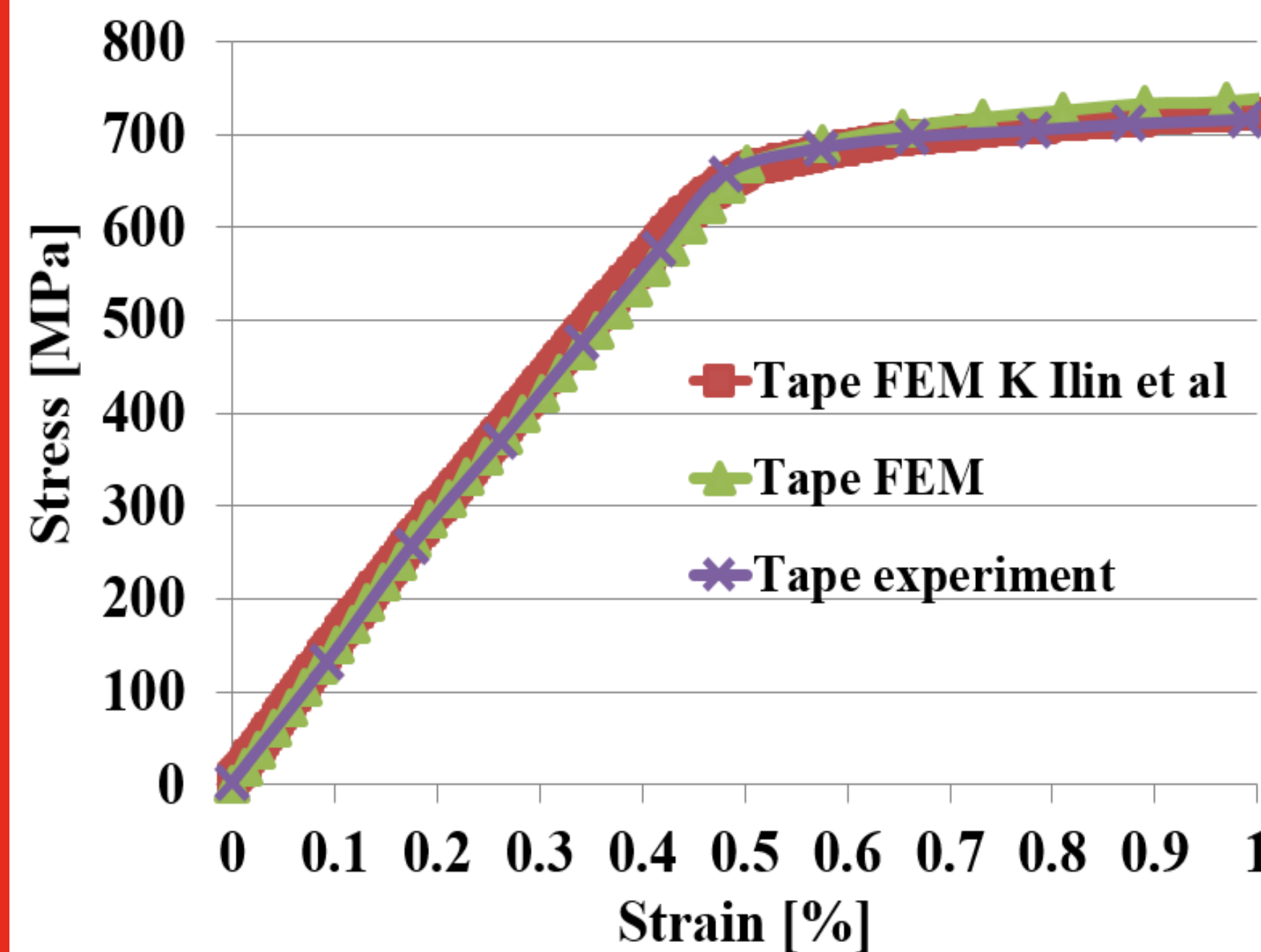


Fig. 1. The stress-strain curves at RT for the SCS4050-AP tape. Comparison of the tensile experiments and modelling results with FEM results reported by K Ilin et al [6].

RESULTS

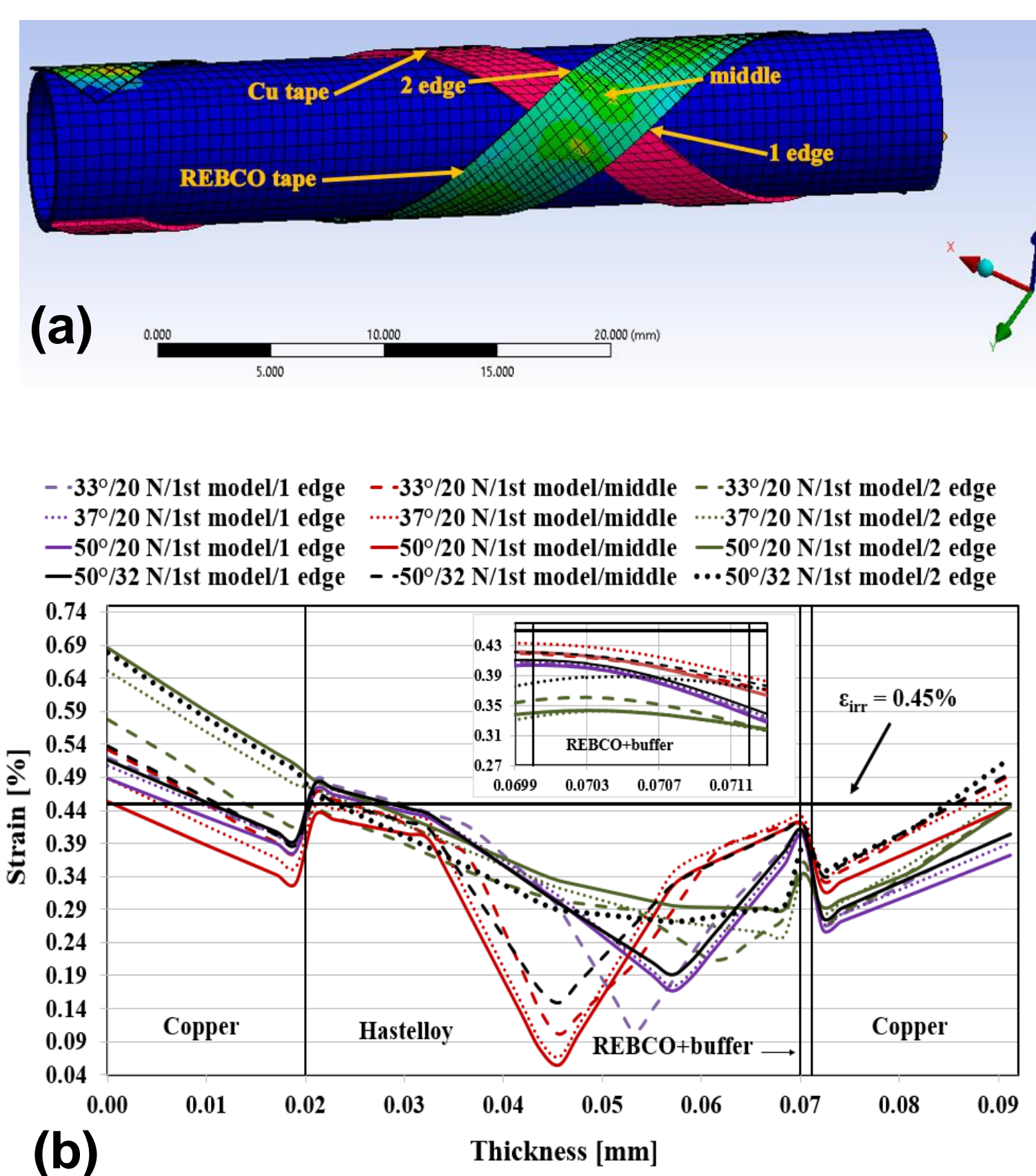


Fig. 2. (a) On the top the schematic of the second model of the REBCO tape wound on copper tube with marked position of transverse strain paths; (b) the distribution of transverse strain in the REBCO tape for the tensile load of 20 N and 32 N and combination of winding angles.

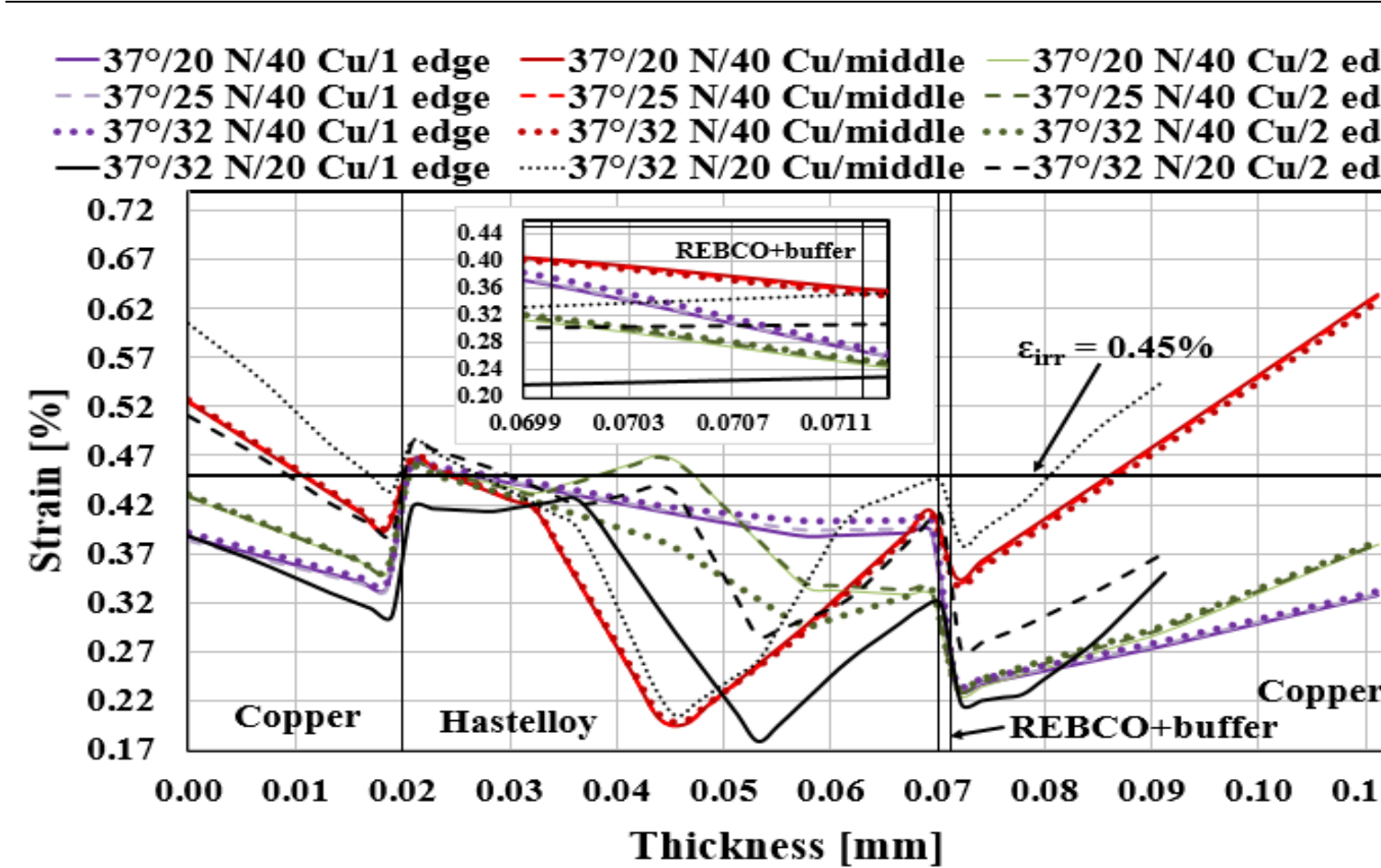


Fig. 4. Intrinsic strain distribution along the transverse paths of REBCO tape under the same 37° winding angle and various tensile forces. Comparison of second model with 20 μm and 40 μm copper stabilization.

Tab. 1. Characteristics of REBCO CC tape SuperPower SCS4050-AP

Tape width	Tape thickness	Cu stabilizer (thickness)	REBCO+Buffer (thickness)	Substrate Hastelloy C-276 (thickness)	Critical current
4 mm	0.0912 mm	20 μm	1.2 μm	50 μm	~ 144 A

B. Finite element analysis

In order to input nonlinear material properties of Hastelloy, copper and REBCO+buffer at RT, elasto-plastic model with bilinear isotropic hardening was used (Tab. 2). In the geometry of tensile simulation was used a piece of tape 2 mm width by 10 mm length, with thickness of layers stated in Tab. 1. We used only one quarter of the sample with symmetric boundary conditions on two sides. Second part of FE analysis was simulation of tension-bending loading. In this work, we build two tape models. First one represents tension-bending loading of one REBCO tape on bare Cu tube with outer diameter of 6.35 mm (dimension of Cu tube was the same for all models). Second one represents tension-bending loading of one REBCO tape on Cu tube with wound Cu tape (4 mm wide and 0.0912 mm thick). In the geometry of the first and second model, pieces of tape with width of 4 mm and length of 20 mm and 50 mm were used, respectively.

Tab. 2. Material properties specified in FE analysis at RT.

	Cu stabilizer	Substrate Hastelloy C-276	REBCO+Buffer
Linear elastic properties			
E [GPa]	80	223	150
σ [MPa]	120	891	
Poisson ratio	0.34	0.307	0.22
Nonlinear elasto-plastic properties			
T [MPa]	21 590	38 166	23 000

(E) Elastic modulus, (σ) Yield stress, (T) Tangent modulus.

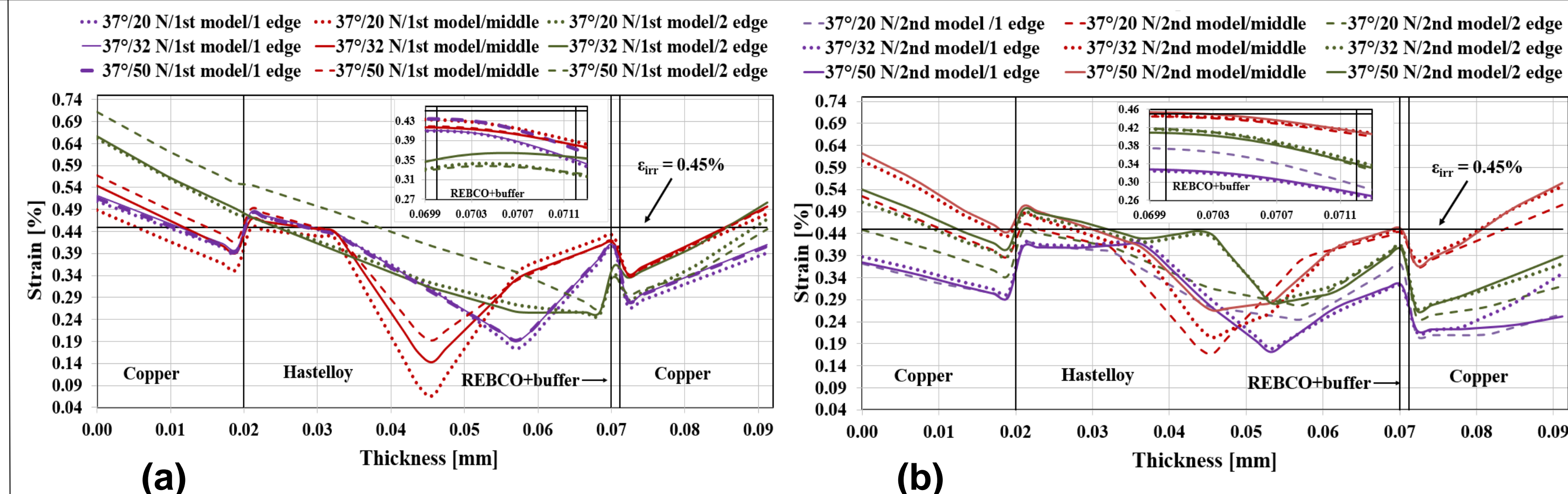


Fig. 3. Comparison of the distribution of transverse strain in the REBCO CC tape wound under winding angle of 37° and various tensile loads (a) first model; (b) second model.

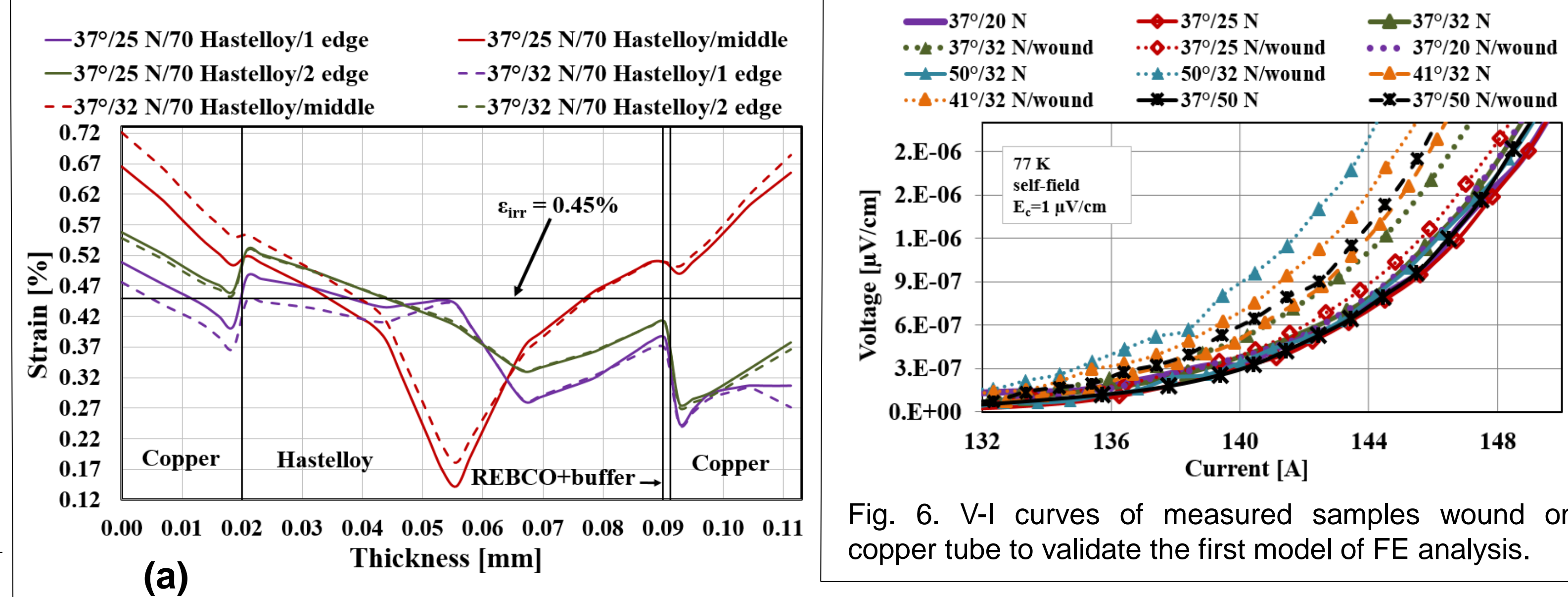


Fig. 6. V-I curves of measured samples wound on copper tube to validate the first model of FE analysis.

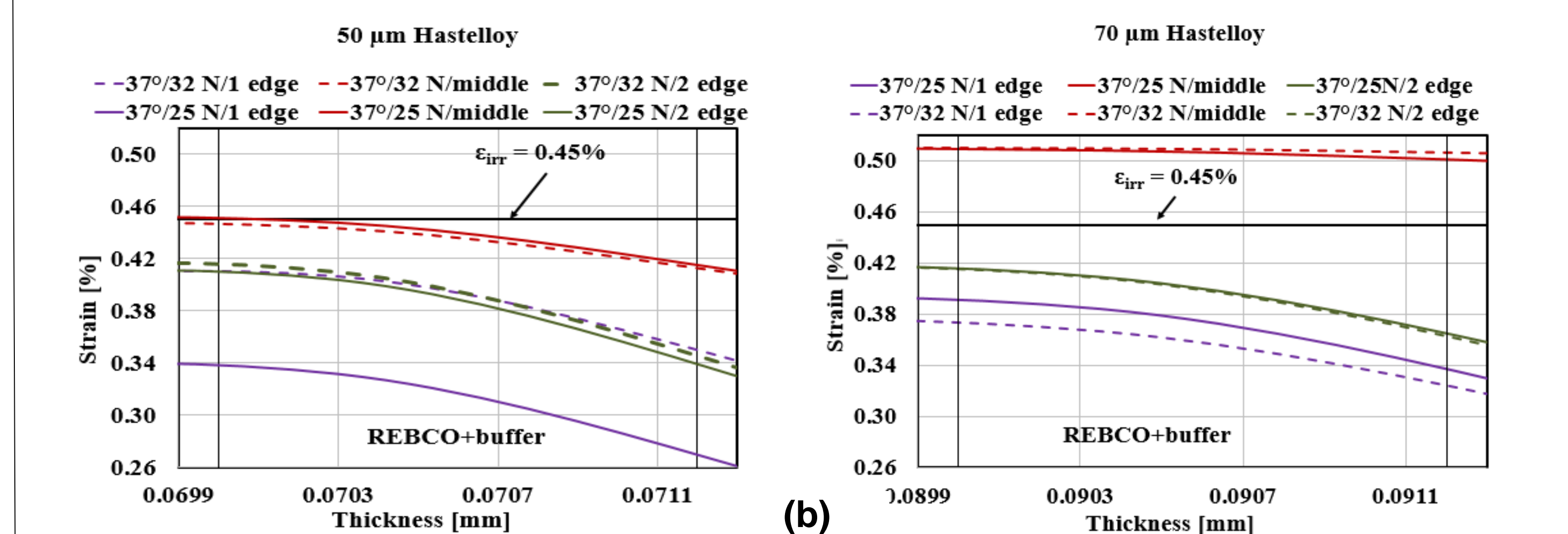


Fig. 5. Intrinsic strain distribution along the transverse paths of REBCO tape under the same 37° winding angle and various tensile forces. Comparison of second model with 50 μm and 70 μm Hastelloy substrate.

CONCLUSIONS

In this study, we consider the start of irreversible degradation of the critical current at the state when the intrinsic strain in the REBCO layer reaches 0.45% ($\epsilon_{irr} = 0.45\%$). As it is seen from the graph profiles the highest values of strain in REBCO layer are generated in the middle parts of tape. As compared with the experimental results plotted in Fig. 6, with regard to the first model, we can consider all winding parameters safe to employ. On the other hand, second model presented overrun of intrinsic strain at 37° and 50 N tensile force. Despite of this fact, lower tensile forces are as well little below the intrinsic strain. This indicates higher mechanical loading of second layer REBCO tapes during the winding process. Moreover, thickness of the layers in REBCO tapes significantly influence their mechanical properties. As it is seen in Fig. 4 and Fig. 5 for winding tapes on round tube it is better to use tapes with thinner substrate. In addition, using thicker copper stabilization (only above the REBCO layer) markedly reduces strain in REBCO.

RELATED POSTERS

See also:
4MP6-12

“Effect of mechanical loading on high temperature superconducting tapes due to winding onto round cables”