ID: TUE-PO1-609-02 1109491899@qq.com

Strain Distribution and Critical Current Characteristics of Individual REBCO Tape and Quasi-isotropic Superconducting Strand Under Bending Loads Based on Layerwise Theory

Wei Pi, Ziyuan Sun, Zhaoyu Zhang, Yang Yu, Ruiqi Wang, Shuwen Ma

University of North China Electric Power, Beijing 102206, China

Introduction

The bending properties of an individual REBCO tape and Q-IS strand are analyzed to investigate the mechanical behaviors of REBCO tapes used alone and stacked in Q-IS strand. Firstly, a 3D model is built by layer-wise laminate theory to analyze the strain distribution of an individual REBCO tape under different tension loads which gives us the stress-strain curve of the REBCO tape. Then the bending characteristics of individual REBCO tape are investigated by experiment, calculation and simulation. In addition, current distribution of Q-IS strand under bending load is also studied in the same way and the critical bending radius under these two circumstances are given.

Configuration of the REBCO Tape

Fig. 1. Cross-section view of the REBCO tape.

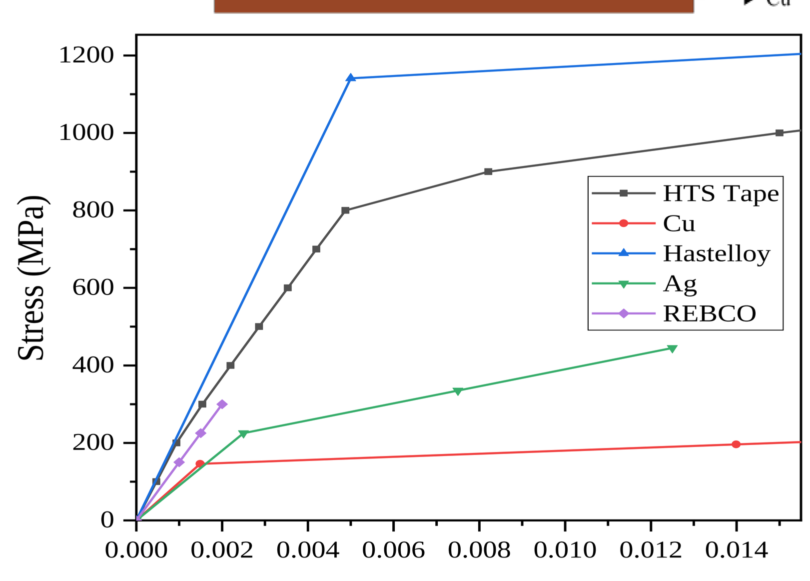

Fig. 2. Stress-strain state of all layers and the REBCO tape.

Calculation Method of Individual REBCO Tape

$$E_{\text{series}} = \frac{1}{\frac{V_{\text{Cu}}}{E_{\text{Cu}}} + \frac{V_{\text{Sub}}}{E_{\text{Sub}}} + \frac{V_{\text{Ag}}}{E_{\text{Ag}}} + \frac{V_{\text{REBCO}}}{E_{\text{REBCO}}}}$$

where V and E represent the volume fraction and Young' s modulus of each material.

$$y = \frac{\sum_{i=1}^{n} n_i h_i y_i}{\sum_{i=1}^{n} n_i h_i}$$

where y represents the position of the neutral axis of REBCO tape in the form of Y coordinate, $n_i = E_i/E_1$, E_i (i=1,2,3,4) represents the Young' s modulus of each material, h_i represents the thickness of each layer, y_i is the Y coordinate of each layer.

$$\varepsilon_{\text{Bending}} = \frac{y - y_{\text{REBCO}}}{R}$$

where y_{REBCO} denotes the Y coordinate of REBCO layer, R is the bending radius.

Normalized I_C is defined as the quotient of actual current divided by critical current in the initial state (I_{C0}) with no strain, as is shown below:

$$\frac{I_C}{I_{C0}} = \frac{1}{w}\int_{-\frac{w}{2}}^{\frac{w}{2}} \frac{J_C(\varepsilon_x)}{J_{C0}} dx$$

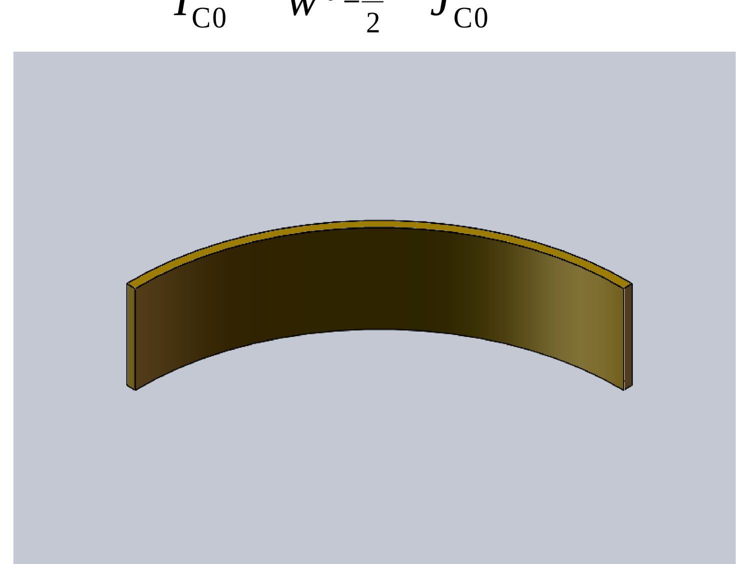

Fig. 3. Schematic view of REBCO tape under out-of-plane bending load.

Calculation Method of Q-IS Strand

$$y_L = \frac{\frac{E_{S_1}}{E_{S_2}} y_{S_1} + y_{S_2}}{\frac{E_{S_1}}{E_{S_2}} + 1} = \frac{E_{S_1} y_{S_1} + E_{S_2} y_{S_2}}{E_{S_1} + E_{S_2}}$$

$$y_R = \frac{\frac{E_{S_3}}{E_{S_4}} y_{S_3} + y_{S_4}}{\frac{E_{S_3}}{E_{S_4}} + 1} = \frac{E_{S_3} y_{S_3} + E_{S_4} y_{S_4}}{E_{S_3} + E_{S_4}}$$

where E_S represents the Young' s modulus of each stack, y_S denotes the Y coordinate of the neutral axis of each stack. After calculation, the value of y_L is -0.086 mm, the value of y_R is 0.086 mm. Then the bending strain of each REBCO tape can be calculated. For tapes in Stack 1 and 4:

$$\varepsilon_{1n,4n} = \frac{y_L - [y_{11,41} + (n-1)\cdot h]}{R}$$

$$\varepsilon_{2n,3n} = \frac{y_L - w_{2,3}}{R} = \varepsilon_{2,3}$$

$$\frac{I_{1C,4C}}{I_{C0}} = \frac{\sum_{n=1}^{20} J_{1C,4C}(\varepsilon_{1n,4n})}{20 \cdot J_{C0}}$$

$$\frac{I_{2C}}{I_{C0}} = \int_{-2}^{0} J_{2C}(\varepsilon_2) dw$$

$$\frac{I_{3C}}{I_{C0}} = \int_{0}^{2} J_{3C}(\varepsilon_3) dw$$

$$\frac{I_C}{I_{C0}} = \frac{I_{C1} + I_{C2} + I_{C3} + I_{C4}}{4 I_{C0}}$$

Simulation

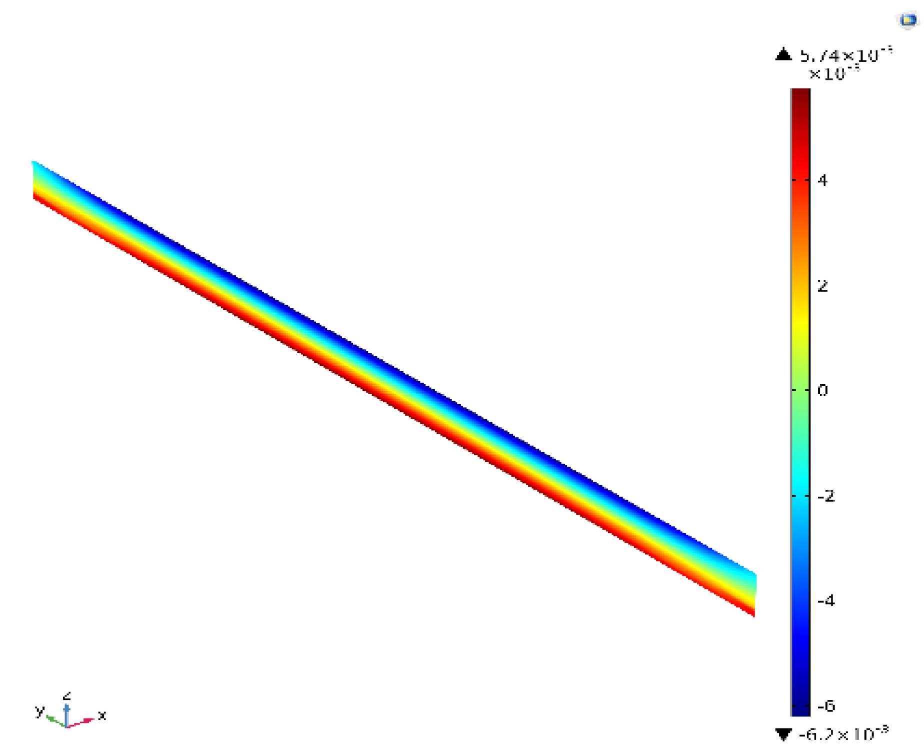

Fig. 4. Cloud chart of strain distribution of the cross section in the middle of the REBCO tape with bending radius of 30mm.

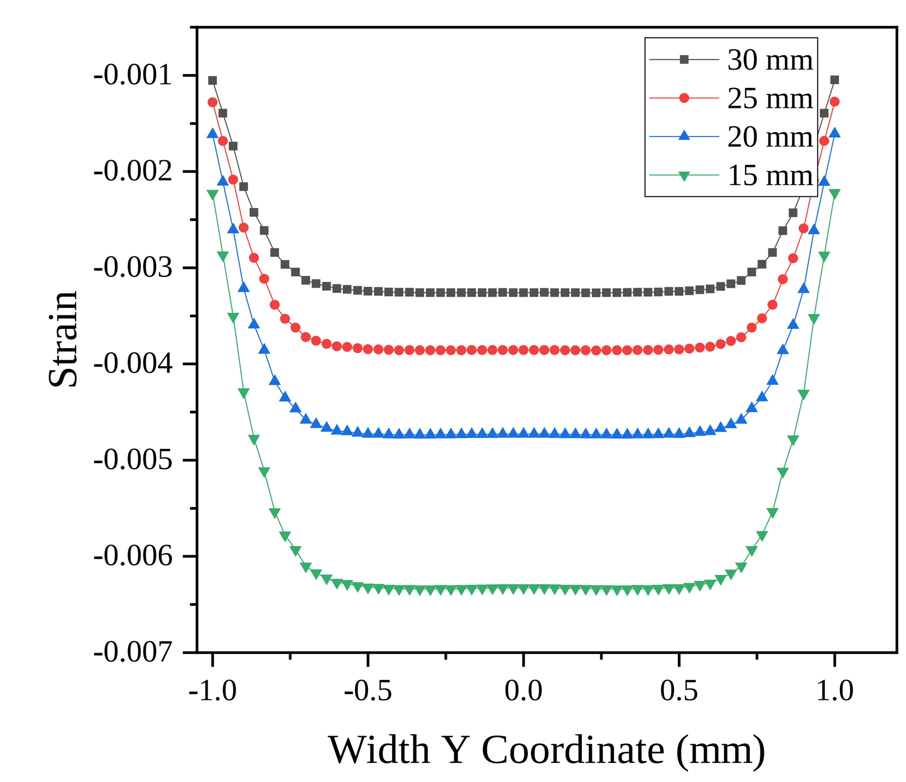

Fig. 5. Strain distribution of the REBCO layer along width direction when bending radius R= 15, 20, 25, 30 mm.

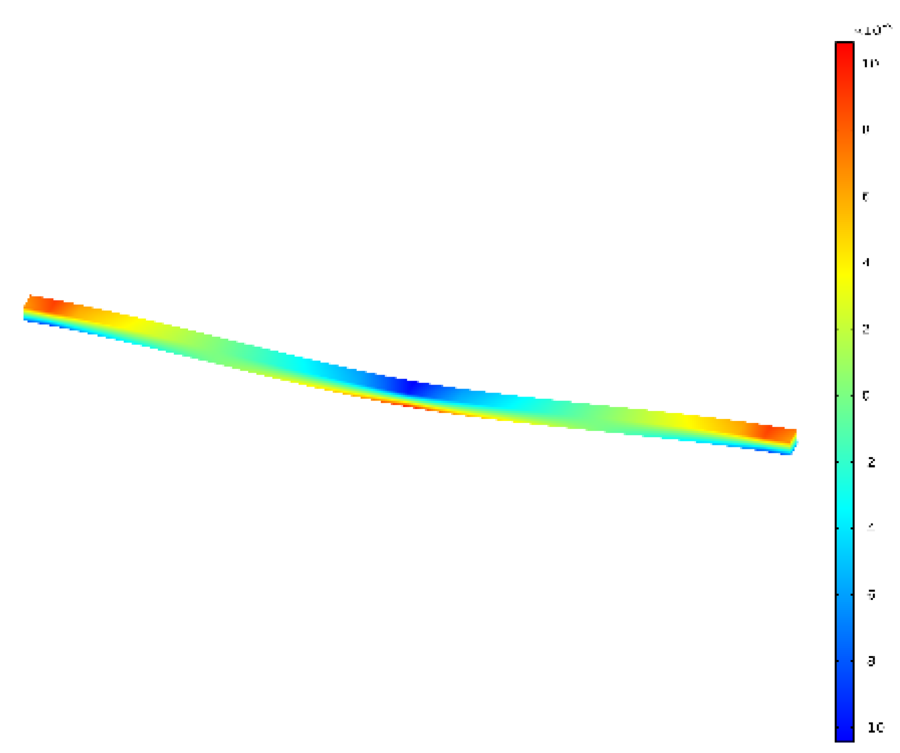

Fig. 6. Strain distribution of Q-IS strand when bending radius is 700 mm.

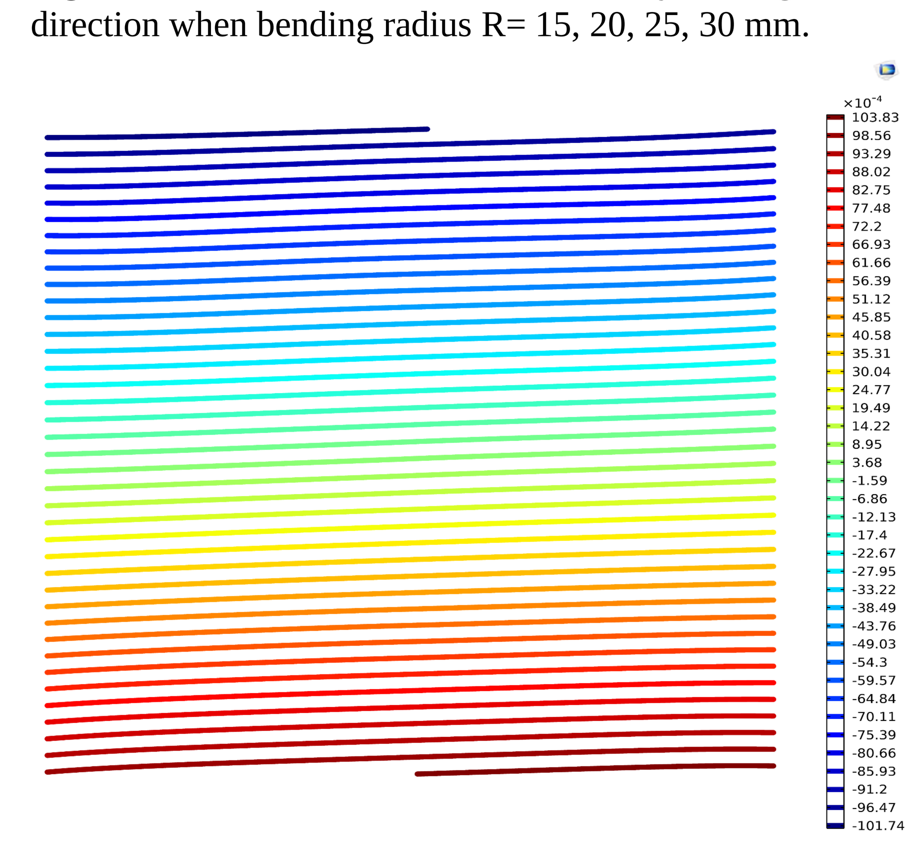

Fig. 7. Isogram of the axial strain of the cross section in the middle of Q-IS strand when bending radius is 700 mm.

Experiment

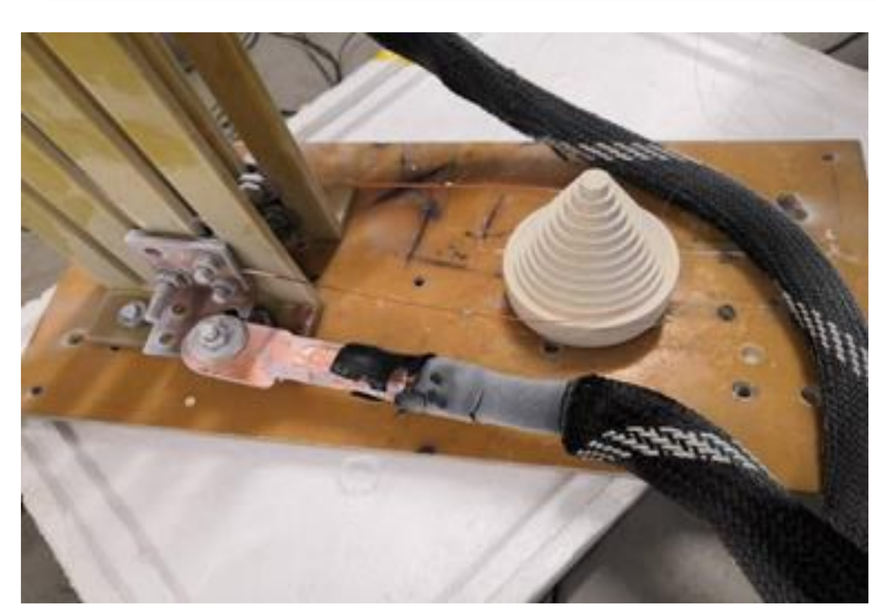

Fig. 8. Schematic view of the strain test device of individual REBCO tape.

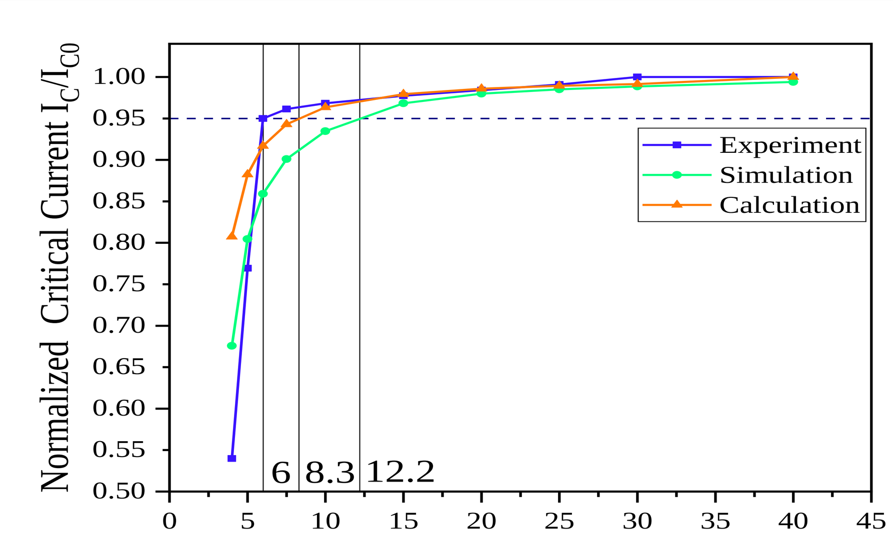

Fig. 9. Normalized critical current of individual REBCO tape versus bending radius in experiment, simulation and analytical calculation.

Fig. 10. Schematic view of the strain test experiment of Q-IS strand.

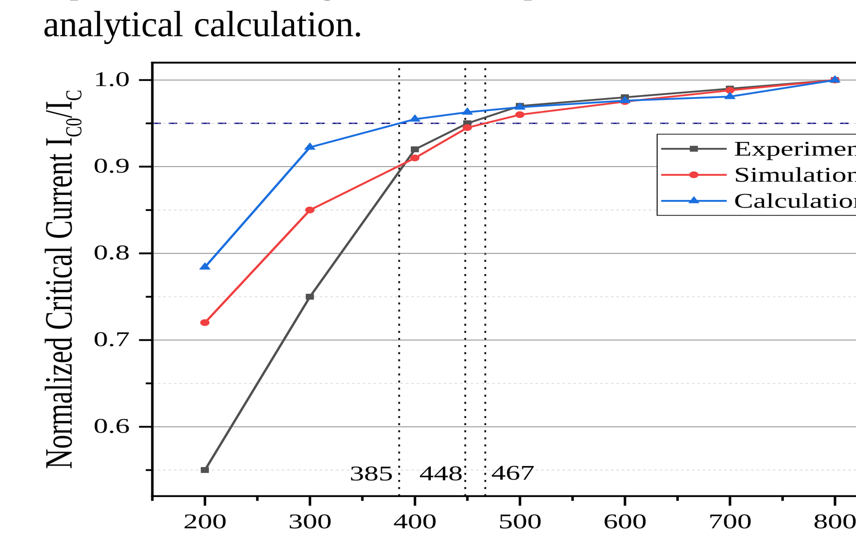

Fig. 11. Normalized critical current of Q-IS strand versus bending radius in experiment, simulation and analytical calculation.

Conclusion

- The critical bending radius of an individual REBCO tape is very small as to less than 10 mm while the critical bending radius of Q-IS strand is up to 450 mm.
- Stacking the REBCO tapes to make various kinds of strands and cables can increase the efficiency of an individual REBCO tape and it is promising in practical applications.