Impact of transverse compression on the sub-element RRP Nb_3Sn strand

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1. Introduction

Magnetic resonance imaging (MRI) is one of the most significant development in medical imaging and is an indispensable modality for medical diagnostics because it provides images with exquisite soft tissue contrast and it is completely noninvasive. As we know, the sensitivity, the spatial and temporal resolution of the images increase together with the static magnetic field strength B0.Ultra-high field (UHF) MRI holds promise in attaining clinically relevant information that is meaningful for disease detection, characterization, therapeutic interventions, or monitoring biologic effects of treatment. Especially, UHF MRI opens a new set of opportunities for neuroscience research which can provide scientific information of human brain. At present, the superconducting material of the clinical MRI superconducting magnet is NbTi, however, Nb_3Sn is the best candidate superconductor to build 14 T MRI magnet. A new kind of composite conductor has been preliminary deigned. The composite conductor consists of Rutherford cable and cooper stabilizer with channel, which is similar to Iseult 11.7T MRI conductor. Developing Rutherford cable techniques for composite conductor with High-Jc Nb_3Sn strand is important, and a key issue is control the strand deformation and reduce performance degradation. During cabling, the strand would experience plastic deformation under transverse compression, which causes sub-elements damage and degrades the transport performance and residual resistivity ratio (RRR) . In order to study the strand sensitivity to such deformation, it is common practice in the superconducting community to rolling single strands. In this paper, the impact of transverse compression on the sub-element RRP Nb3Sn strand before heat treatment was studied with finite element model (FEM) and experiments, the FEM results and experiment results are compared and analyzed.

2. Model

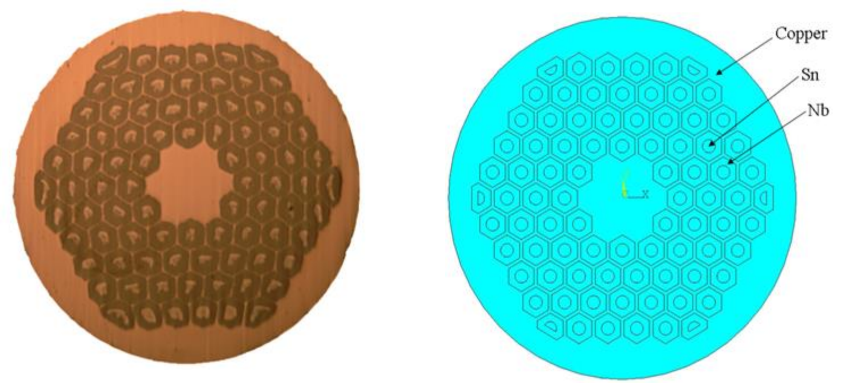

Fig.1. The cross section of the OST RRP 84/91 strand and 2D model of the strand.

The simulations were performed with a 2D model using ANSYS. Element PLANE183 with plane strain option was used to model the strand , CONTACT172 and TARGE169 were used to simulate the contact behavior. The contact elements used in the analysis overlay all regions where a contact might occur. Deformation was applied by a flat plates to wires before heat treatment. The wire diameter was reduced by amounts of 10% to 30% in incremental steps of 5%. Any different load orientations should be considered, but compared experiment results, only one load orientation were considered, the wire displacement was applied on the side of the hexagonal superconducting area.

Item	Unit	Value
Stack design		RRP
Diameter	mm	0.806
Critical current density @12T,4.2 K	A/mm^2	>2200
Cu:non-Cu		1
Size of Sub-element(SE)	μm	60
Number of SE		84/91
Material of barrier		Nb
Thickness of barrier	μm	3.0
Copper spacing between SE	μm	8.0

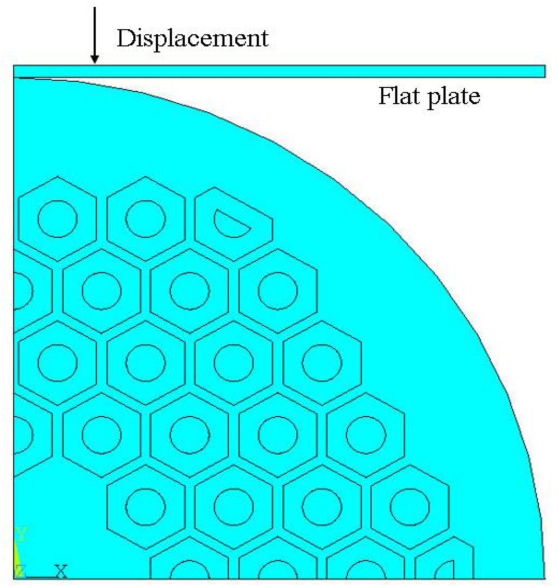

Fig.2. Displacement direction.

3. Results and Discussion

☐ Experiment

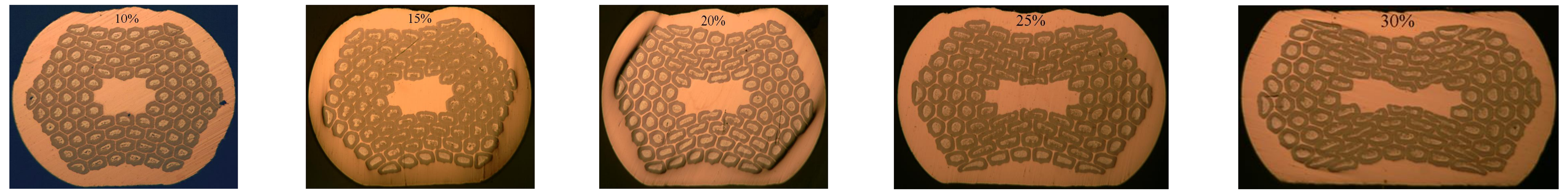

Fig.3. Sequence of pictures showing the impact of increasing deformation.

The sub-element along the 45 ˚ plane has more several deformation and the deformation of sub-element form an ‘X’ shape. The largest deformation spread out from the center along the 45˚ plane.

☐ Simulation

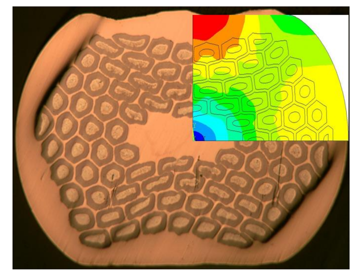

Fig.4. RRP strand after 20% reduction in diameter

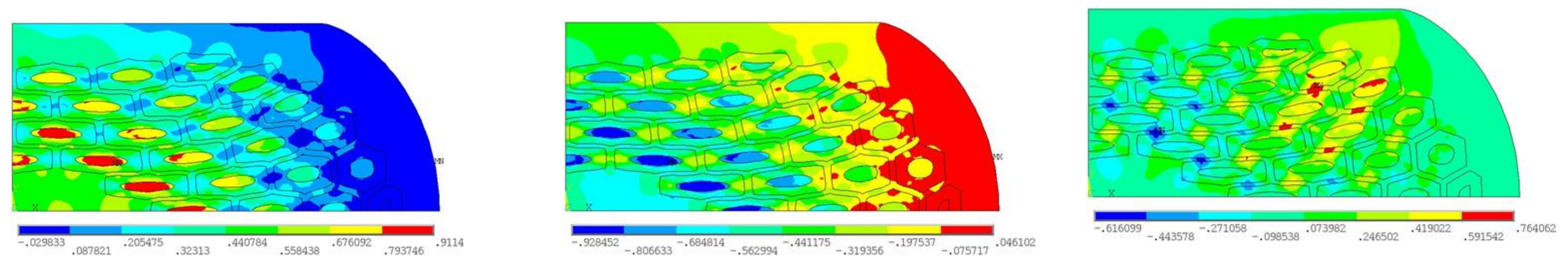

Fig.5. Strain_x , Strain_y and Strain_xy component at 20% deformation.

The observed deformation is shown together with the FEM simulation result. The match is perfect and the calculation give a suitable description of the overall behavior of the real strand. Compared with the observed deformation, the FEM simulation result was also shown that the shear plane titled by about 45˚ with respect to the y axis. It divides the cross section of the strand into four regions: the regions on both sides are less sensitive to the transverse compression, whilst the top and bottom regions are sensitive to the transverse compression, especially junction area along 45˚ plane.

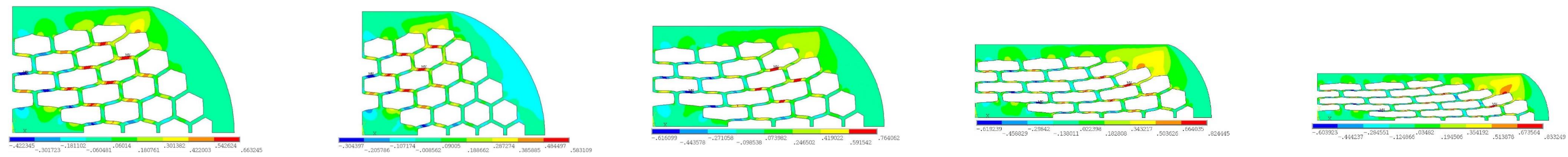

Fig.6. Sequence of pictures the strain_xy component of increasing deformation.

In RRP Nb_3Sn composite strand, the out walls of the Nb bundles merge together if the copper spacing between sub-element become thin enough. The copper matrix is similar to a frame structure, which shear resistance is poor. Fig.6 show the strain_xy component with different deformation from 10% to 30% in incremental steps of 5%. As shown in Fig.6, the maximum strain_xy component along the shear plane, which is consistent in that an experimental study, as shown in Fig.3.

4. Conclusions

Experiment and FEM has been carried out to study the impact of the transverse compression on the sub-element RRP 84/91 Nb3Sn strand, it indicate FEM analysis is a powerful tool to simulate severe plastic deformation of strand. The high deformation of the sub-element under transverse compression form an “X” shape. Correlating the finite element results to experimental images give the strain distribution of the strand. Compared with different stain components, strain_x was more sensitivity to the transverse compression. The maximum strain_xy in the copper spacing between sub-element along the 45˚ shear plane, which agrees with the experimental results. Based on the above analysis, it can provide a basis for the design of the Rutherford cable.