Fusion Engineering and Design 109–111 (2016) 1267–1271

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Performance optimization of internal tin process multifilamentary Nb_3Sn strands

Ke Zhang [a,b,c,*], Pingxiang Zhang [a,b,c,d], Yigong Shi [b,c], Jianwei Liu [b,c], Huixian Gao [b,c], Jianfeng Li [b,c], Xianghong Liu [b,c], Yong Feng [b,c]

[a] State Key Laboratory of Solidification Processing, Northwestern Polytechnical University, Xi'an, Shaanxi 710072, China
[b] Western Superconducting Technologies Co. Ltd, Xi'an, Shaanxi 710018, China
[c] State Engineering Lab. of Superconducting Material Preparation, Xi'an, Shaanxi 710018, China
[d] Northwest Institute for Non-ferrous Metal Research, Xi'an, Shaanxi 710016, China

HIGHLIGHTS

- J_c increases by adding Sn cores in the interspaces, hysteresis loss increases at the same time.
- Enlarger the number of filaments with the same Sn proportion will increase J_c and hysteresis loss.
- Cu split adopted in each sub-element leads to a low hysteresis loss.

ARTICLE INFO

Article history:
Received 8 September 2015
Received in revised form
10 December 2015
Accepted 17 December 2015
Available online 29 December 2015

Keywords:
Nb_3Sn
Internal tin process
Critical current density
Hysteresis loss

ABSTRACT

In this study, internal tin process Nb_3Sn strands for the International Thermo-nuclear Experimental Reactor are developed in Western Superconducting Technologies. Short cable-in-conduit conductors manufactured with these strands have been qualified. Mass production is accomplished, and all the performances of the strands meet the requirement of ITER project. Besides, more researches on the effect of strand design on critical current density and hysteresis loss for Nb_3Sn strands are carried out. It is found that critical current density can be enhanced by reducing filament diameter and increasing Sn content, and hysteresis loss of the strands can be significantly reduced through Cu split adopted in sub-element.

1. Introduction

Nb_3Sn superconducting strands are widely applied in magnets which can generate high magnetic fields of over 10 T. In the fabrication of multi-filamentary Nb_3Sn strands, various methods, such as internal tin process, bronze process and power-in-tube process, are developed. As a big international cooperation project, International Thermo-nuclear Experimental Reactor (ITER) project aims to produce fusion energy. However, high magnet field requires Nb_3Sn strands to have higher non-copper current density J_c and lower hysteresis loss.

Many factors are important in strand design for obtaining high J_c. Firstly, an appropriate ratio of Nb to Sn can produce higher J_c. Cu–Sn alloy is used as the Sn source in bronze process, while Sn or Sn–Ti alloy is applied in internal tin process. The solubility limit of Sn in Cu is 15.8 wt.%, which restricts the J_c of bronze process strands. In internal tin process strands, wider range of Sn content will realize higher J_c. Secondly, filament diameter is another important parameter for J_c. Finer filaments will react more fully than thicker filaments in a same heat treatment cycle, which leads to a higher J_c. Finally, J_c could be improved by either increasing Nb_3Sn layer formation rate or refining the grain size by Ti added in Cu–Sn alloy or Sn core.

It is well known that hysteresis losses are mainly caused by filaments bridging in internal tin Nb_3Sn strands. Many investigations on loss reduction by optimizing strand design and twist pitch have been reported. Gregory et al. [1] reduced losses by changing the conductor design. Two ways were carried out via different designs of fins to subdivide sub-elements with a tubular approach. Pantsyrny et al. [2] summarized that hysteresis losses of strands of 0.8 mm in diameter decreased with twist pitch reduction,

* Corresponding author at: State Key Laboratory of Solidification Processing, Northwestern Polytechnical University, Xi'an, Shaanxi 710072, China.
E-mail address: zhangke@c-wst.com (K. Zhang).

http://dx.doi.org/10.1016/j.fusengdes.2015.12.046
0920-3796/

Table 1
Parameters and performances of Nb_3Sn strands.

	ITER type	Type A	Type B	Type C	Type D
Number of sub-elements	19	19	37	19	19
Number of filaments	3040	3040	5920	2964	2964
Sn spacer	No	Yes	No	No	Yes
Cu split	No	No	No	Yes	Yes
J_c (A/mm^2) @4.2 K, 12 T	1011	1156	1108	966	1035
Hysteresis loss (mJ/cm^3) @4.2 K, ±3 T	466	529	610	305	302

especially for twist pitches less than 12 mm. Zhang et al. [3] also studied the influence of twist pitch on hysteresis loss of internal tin process Nb_3Sn strands. In their work, the hysteresis loss of non-Cu area of the untwisted sample was 1023 mJ/cm^3 (4.2 K and ±3 T) and that of strands after twisting process dropped to 874 mJ/cm^3.

WST has developed both bronze process and internal tin process Nb_3Sn strands [4]. The short cable-in-conduit conductor (CICC) samples named TFCN2 and TFCN4 cabled using internal-tin process Nb_3Sn strands have been tested in the SULTAN facility at CRPP [5]. In the SULTAN test the conductor current is 68 kA and the background field is 10.78 T. The T_{CS} of two samples fulfill the ITER specification. Until now, over 30 tons of internal tin process Nb_3Sn strands have been fabricated and delivered for ITER TF coils.

In this paper, some studies on strand design and heat treatment at Western Superconducting Technologies (WST) to optimize the performance of Nb_3Sn strands produced through internal tin process are reported.

2. Experiment

Multifilamentary Nb_3Sn strands with a diameter of 0.82 mm were fabricated through internal tin process in this work. The

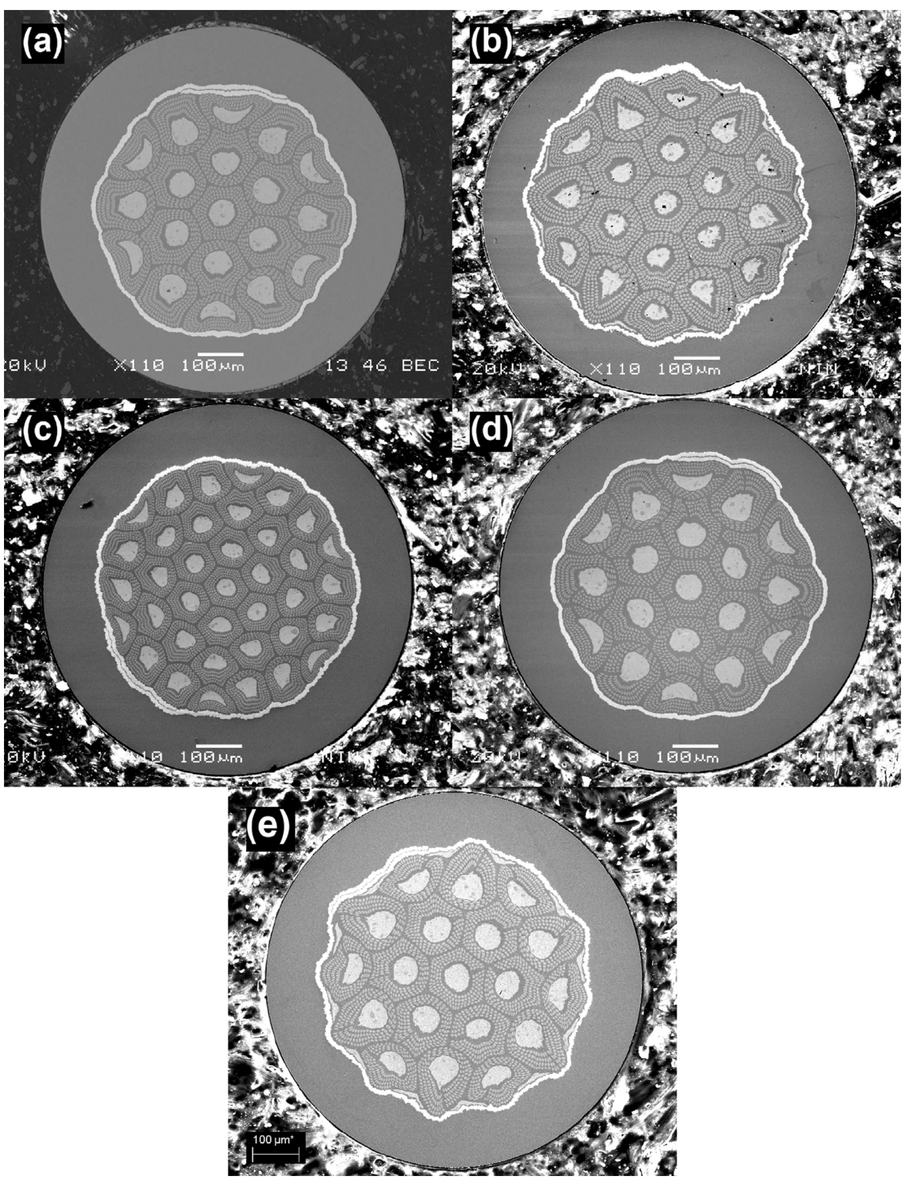

Fig. 1. Cross sections of internal tin process Nb_3Sn strands with different designs: (a) ITER type, (b) Type A, (c) Type B, (d) Type C, and (e) Type D.