Analysis of Nb_3Sn strand microstructure after full-size «SULTAN» test of ITER TF conductor sample

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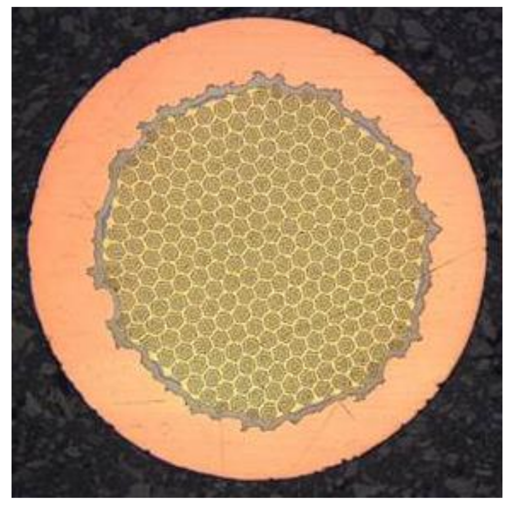
Abstract

The study of defects generated in superconducting filaments of Nb_3Sn strands under electromagnetic and thermal cycling was carried out for the ITER TFRF3 cable-in-conduit-conductor (CICC) sample passed final testing at the SULTAN test facility. The TFRF3 sample was manufactured from the qualification RF Toroidal Field CICC. This sample showed very good stability and EM cycling resistance among other ITER conductors. Amongst the effects that may contribute to the CICC degradation, damage of the strands in form of filamentary cracks is considered as an important factor. Using Laser Scanning Microscope, we analyze number, types, and distribution of defects in filaments of Nb_3Sn strand samples extracted from different petals of TFRF3 in dependence on a strand location in cross–section (the center of petal, nearby the spiral, nearby the outer jacket) in high field zone (HFZ). The results about the defects distribution are presented and discussed.

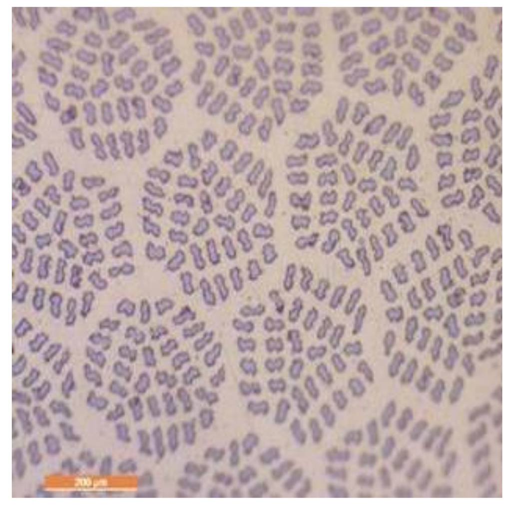
Experimental Procedure

Nb-Sn Strand

Bronze Nb3Sn strands are used for TF Conductor in Russia.



Cross Section of the Strand

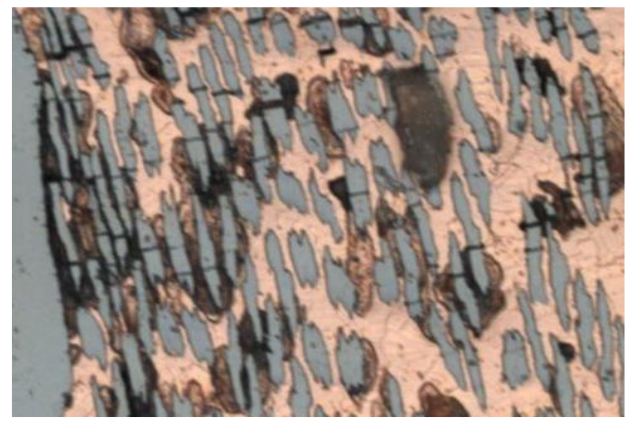


Fragment of filamentary zone

Two References Samples

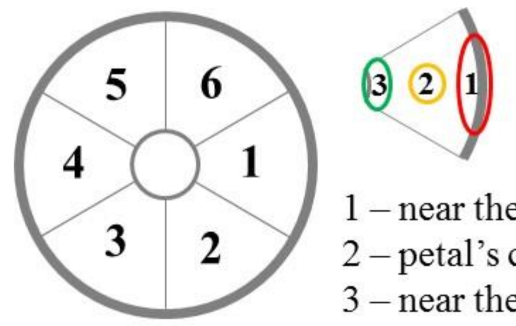
The applicability of the samples preparation technique was proved on two reference samples (strand just after heat treatment and strand after heat treatment and repeated manual bending)

Strand just after Heat Treatment

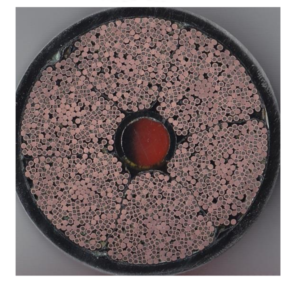


Strand after Heat Treatment and manual bending

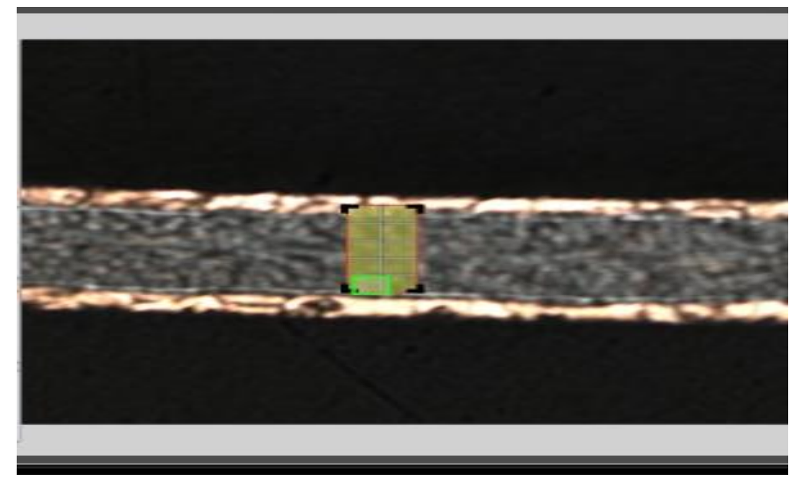
Strands Sampling



1 – near the jacket
2 – petal's center
3 – near the spiral

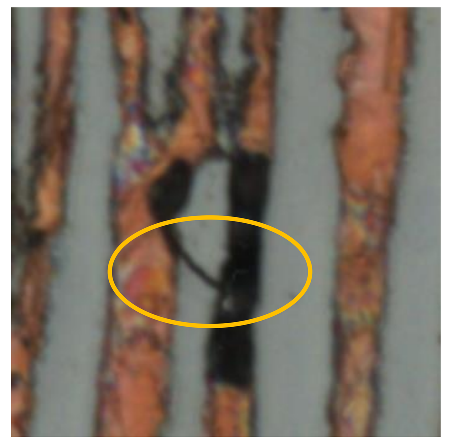


Conductor Cross Section

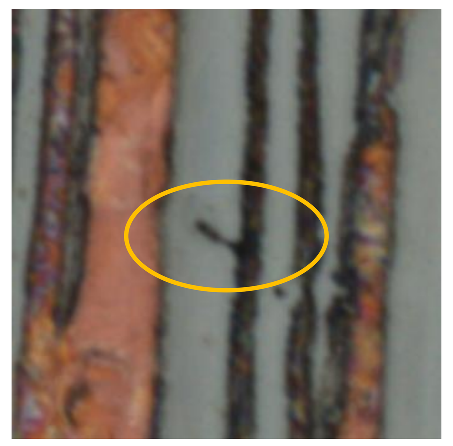


Kinds of Defects

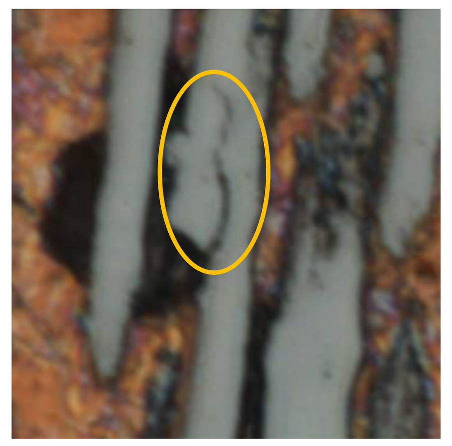
Cracks perpendicular to filament axis



Cracks where break line completely crosses the filament at an angle between 90° and 45° to axis



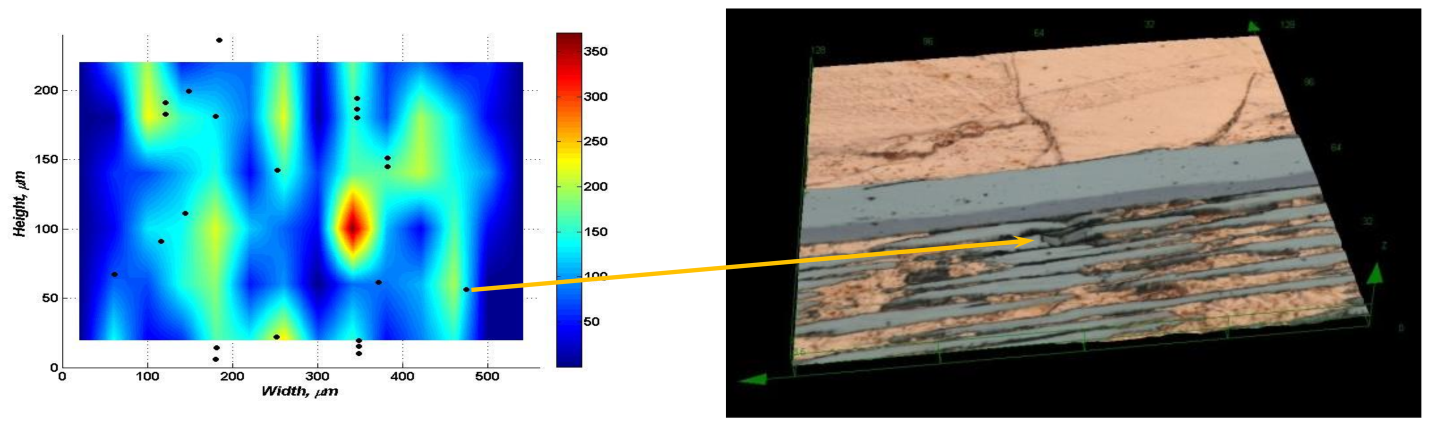
Cracks extends over a half of filament width



Longitudinal cracks, where break line does not touch any side of superconducting filament

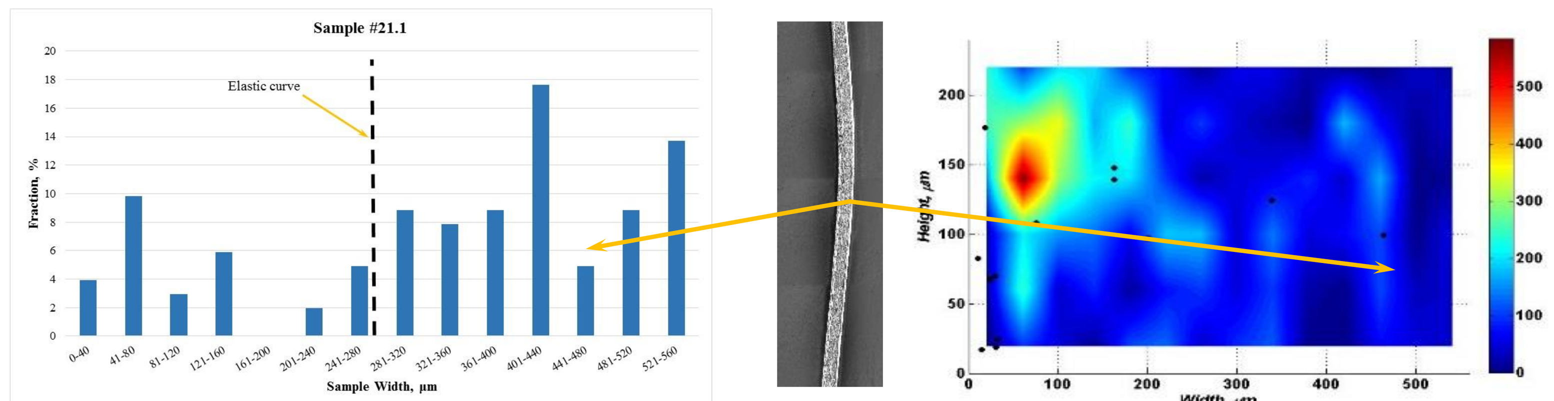
Results

Effect of Local Void Fraction



The void-induced perpendicular cracks are the most common. We found an evidence of a local void fraction influence on the crack formation.

Effect of Local Strand Curvature



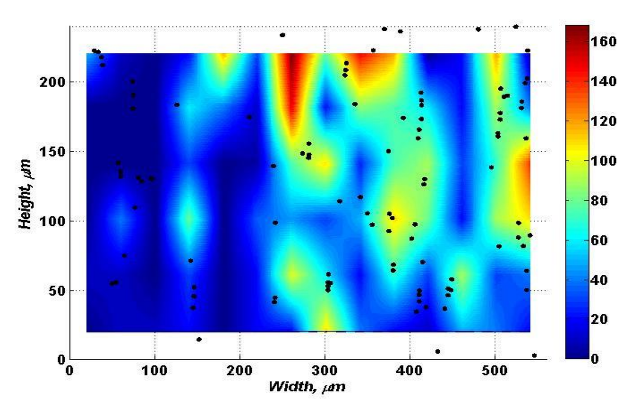
In common, local curvature of strand influences on cracks formation with a tendency of cracks appearance at the extended (convex) side of the sample. In turn the high local void fraction can influence in the opposite way and cracks can form in compressed side of the sample.

Effect of Strand Position in Conductor Cross Section

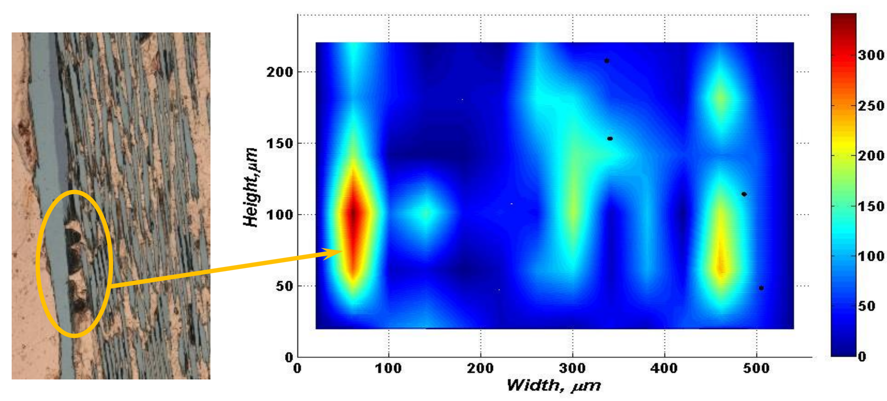
Petal #	Strand Position in Petal		
	Near jacket	Near spiral	In center
1	46±16	29±8	24±10
4	109±37	34±14	27±10

A significant difference of cracks number (almost in two times) in strands taken off near jacket and near spiral and in the centre of petal.

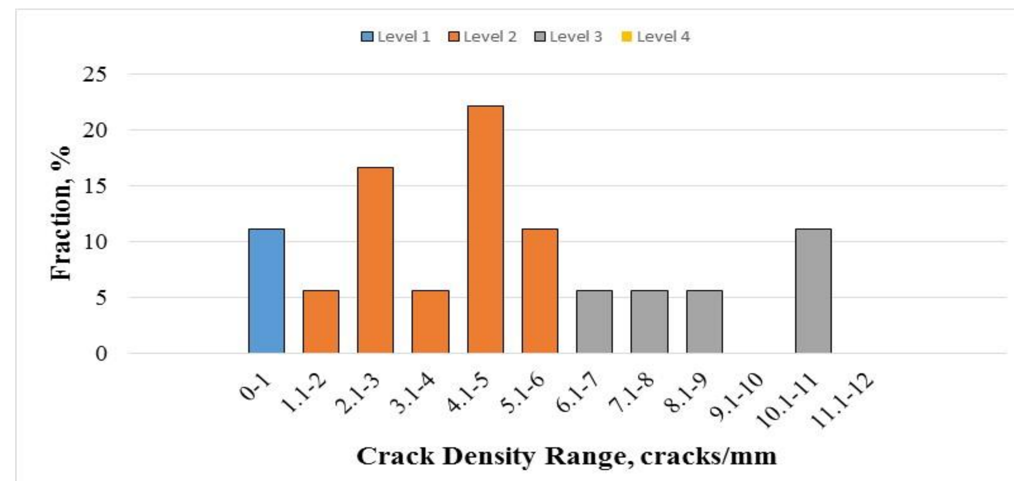
Conclusion and Discussion



A void area in bronze matrix and cracks location in the sample with the highest cracks number



A void area in bronze matrix and cracks location in the sample with the lowest cracks number Pick intensity of void area on the left side of the picture corresponds to several large voids located beyond the filament zone



It seems the strand is less damaged than other strands extracted from bronze route based CICC 's

Summary

-Well distributed Nb_3Sn bronze strands (with higher number of sub-elements) seem more convenient for CICC manufacture due to their resistance against bending;
- Non-uniform distribution of voids in bronze matrix (in particular, clustering of large voids) can result in additional filament damage because most of filament cracks are void-induced.