Analysis on full-size ITER TF jacket tubes after tensile test at 300K, 77K and 4.2K

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Introduction

The International Thermonuclear Experimental Reactor (ITER) project is a worldwide research experiment that aims to explore nuclear fusion as a viable source of energy for the coming years. The TF coils are constructed using Nb_3Sn CICCs due to the requirement of high magnetic field. The 316LN stainless steel material has been chosen as the TF jacket, due to its good mechanical properties at elevated temperatures, its excellent corrosion resistance and fabricability.

In order to reflect the true mechanical performance of the jacket material at 4.2 K preferably and to evaluate its suitability as ITER TF jacket, tensile tests on the full-size TF conductor jacket tubes were carried out at 4.2 K, 77Kand 300 K. The 4.2 K test results present 28.8% for EL, 1100MPa for 0.2% YS and 1490 MPa for ultimate tensile strength, which are over the ITER requirements. Indeed, the full-size tubes failed not only along the slip band but also across the slip band.

In this paper, we give thorough tests of the full size tube after tensile test, and provide a possible mechanism underlying the stress-strain and free energy linking to structure transformation and reveal a profound connection between the grain morphology changes and phase deformation.

Conclusion

- The full-size tubes of ITER TF jacket have been analyzed after tensile test at 300K, 77K and 4.2K.
- From the optical images, some ripples have been obviously visible on structure of the fractured tube after 4.2K test; whereas, the ripples cannot be seen on the other two tubs.
- Detail analysis shows that the results of the fractured tube at 4.2K, whose tensile breaking site in the exact middle place of tube, are more reliable.
- The maximum structure deformation is always found in the exact middle position of the tube, the same to the XRD results and TEM images data, and then decrease gradually along the axis direction from the fracture to the ends.

Experimental Procedure

The tensile tests were carried out by a testing machine (MTS-SANS CMT5000), which was conducted in displacement control with a strain rate of 5×10-4 1/s in accordance with ASTM E1450. The cryogenic environment was obtained through immersing the whole full-size tube into liquid helium or nitrogen.

Specimens in the form of discs with 6 mm in diameter were cut out from the tensile fractured tube parallel the longitudinal directions by wire-electrode cutting, named as site 1 to 5 (in Figure 1), then were examined by using in-situ temperature dependent X-ray diffractometer (XRD) measurement. Specimens (1.5 × 4 mm) for magnetic measurements were also taken from the tensile fractured tubular TF conductor jacket, with the same position as site 1 to 5. Selected specimens were also detected by optical microscopy and transmission electron microscopy (TEM) analysis.

Results and Discussion

Optical Characteristics

Fig. 1.The optical images of the fractured full-size tubes at 4.2K, 77K and 300K.

➢The Here, we developed special design. First, the ends of the tube had been weld with another ring, which could make sure the tightly hold; second, we put an additional stuff inside the ends to guarantee the successful tensile test.

➢See that closely, some ripples have been obviously visible on structure of the fractured tube after 4.2K test; whereas, the ripples cannot be seen on the other two tubs.

➢For 4.2K test, the tube failed not only along slip band but also across slip band, and the appearance of macroscopic slip bands going with the occurrence of load jumps is observed clearly.

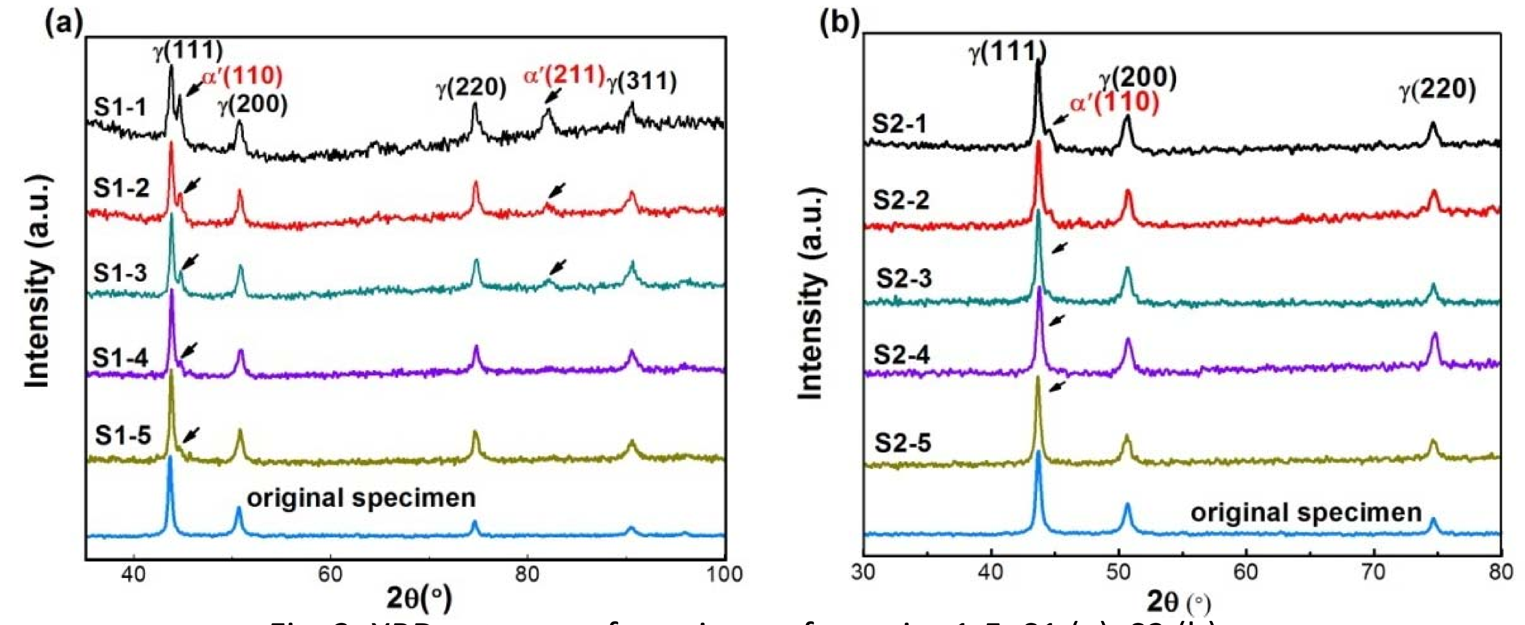

Fig. 3. XRD patterns of specimens from site 1-5, S1 (a), S2 (b).

Distinctly, original specimen and specimens from fractured tubes after tensile test at 300K and 77K give typical of a face centered cubic lattice (fcc) structure of γ-austenite peaks.

XRD patterns of specimens S1 and S2 exhibit not only γ-austenite peaks but also tensile stress induced α'-martensite peaks. contrast to S1, peaks of α'-martensite in S2 is clearly weaker, meaning the less force induced α'-martensite deformation in S2. The peaks of the remaining γ-austenite decrease slightly, whereas do not shift.

Results and Discussions

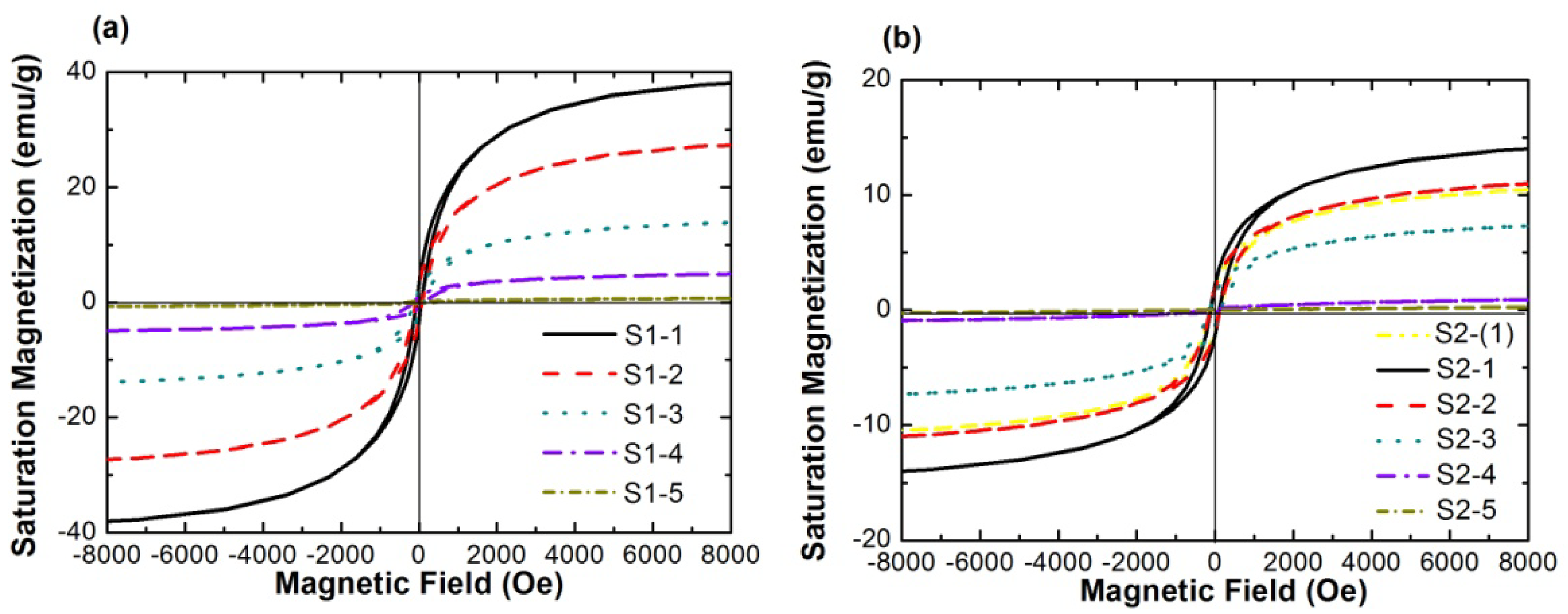

Fig. 2. Magnetization loops for S1 (a)and S2 (b), the magnetic field was increased from -80000 Oe up to +80000 Oe and again back to -80000 Oe.

Both S1 and S2 give magnetic property, to explore process of structural change along the tube we tested several sites.

Table 1. The chemical composition of the TF conductor jacket material after tensile test at 4.2K.

Specimen	M_s (emu/g)	M_r (emu/g)	H_c (Oe)	$V_{\alpha'}$ (%)
S1-1	40.2	3.0	64	26
S1-2	28.5	2.8	77	18
S1-3	14.5	2.1	113	9
S1-4	5.2	1.0	145	3
S1-5	0.4	0.2	333	0.3
S2-(1)	10.5	1.74	123	6.8
S2-1	14.2	2.13	111	9.2
S2-2	11.1	1.82	123	7.2
S2-3	7.4	1.36	140	4.8
S2-4	0.9	0.13	242	0.6
S2-5	0.3	0	-----	0.2

As we all know, magnetic property has no relationship with the γ-austenite structure of 316LN SS, whereas is due to the force induced α'-martensite structure . Taken together, we think after tensile test only at 4.2K, the structure of the tube has changed. No matter the breaking position is, the maximum deformation is thought to be at around the middle site of the tube, then decrease along axis direction from the fracture to the ends.

Changes in Microstructure

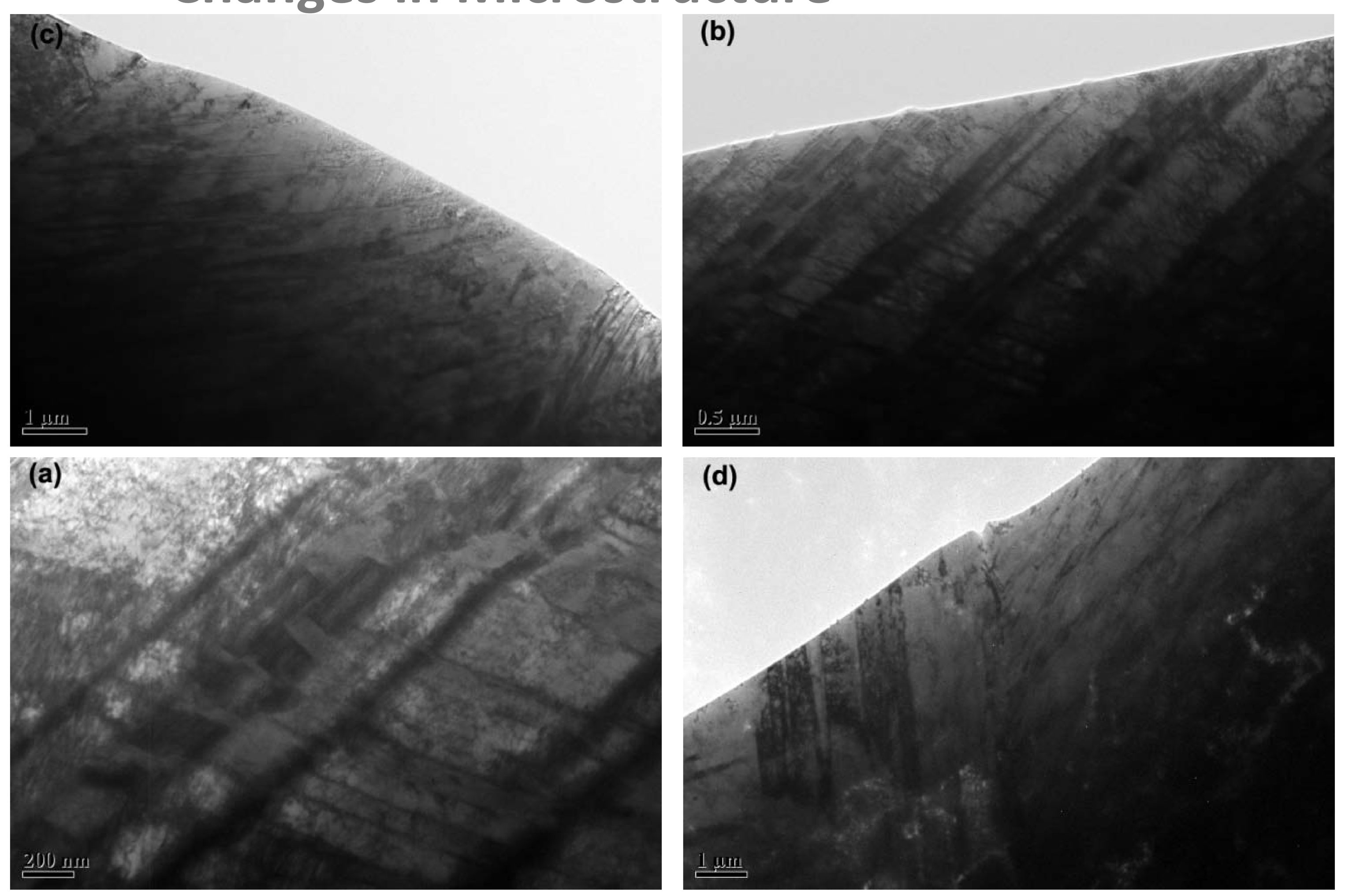

Fig. 4. TEM images of the specimen at site 1, of S1 (a) and (b), of S2 (c) and (d).

➢The bright-field images of specimens S1 and S2 were investigated by TEM and are shown in Fig.4. Pronounced deformations are identified in both images, except that the deformed bands are much more obvious for S1.

➢Additional, the deformed twins, martensite microstructure and intersection between martnesite and deformation twins are visible as a typical phenomenon taking place on intersecting {111} planes. The bands may be produced by slip on closely spaced slip planes.

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