§6. Stress/strain and Their Hysteretic Effects on the Critical Current of Superconducting Wire

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1. Introduction

Due to its high Bc_2, Nb_3Sn superconducting wires are widely used for high field superconducting magnets. However the critical current, I_c ,of them is known to be very sensitive to applied stress/strain. Therefore the effect of stress/strain on I_c has to be evaluated. In this research, internal Sn diffusion process and bronze process Nb_3Sn wires for ITER TF coils (heat treated with 873K, 600h) with diameter 0.8mm have been evaluated. In this report, observations of I_c degraded sample wires of internal Sn diffusion process by Scanning Electron Microscope (SEM) or Transmission Electron Microscope (TEM) are shown. Detailed observations of irreversible damages of micro structures in a wire caused by axial tensile stress were made.

2. Observations

Fig.1 shows a cross section and a longitudinal section of a wire of internal Sn diffusion process, and Fig.2 shows SEM observations of (a) as received and (b) after loaded wires (50% I_c of as received wire). White areas in a picture of Fig.2 are Nb_3Sn filaments. The 2nd filament from the top in Fig.2(b) was broken like to pieces, and a large void between right of the 1st and the 2nd filaments was generated. Since EPMA analysis of the second filament suggested the existence of a small amount of Cu there, a kirkendall void was generated during Sn diffusion process and later it grew by stress concentration of tensile loading. As generally predicted, a kirkendall void was generated at Cu layer between filaments and near initial Sn core. However the voids of as received wire were not obviously observed yet as shown in Fig.2(a), but they became obvious as being loaded. Fig.3 shows TEM observations of a perpendicular plane of Fig.2. The filaments of the after loaded wire were slightly elliptic and the inner angle of the kirkendall void of the wire became acutely. A grain size of this internal Sn diffusion process filament was about 0.5μm. A crack along grains boundary was observed in Fig.3(b). This crack is, for example, parallel to the one in 5th filament from top of Fig.2(b), therefore it also parallel to the current path and the filament might transmit some current regardless of a crack. In addition to that, there was no damage filament like 4th one from the top in Fig.2(b), so that the wire still kept 50% of initial I_c. I_c degradation is caused mainly by cracks perpendicular to the current path like 3rd filament from the top. These cracks also showed small zigzag path by which the crack along the grain boundary was predicted.

In this way, a damage of a Nb_3Sn wire of internal diffusion process originates from some filaments around a kirkendall void and gradually proceeds by tensile loading.

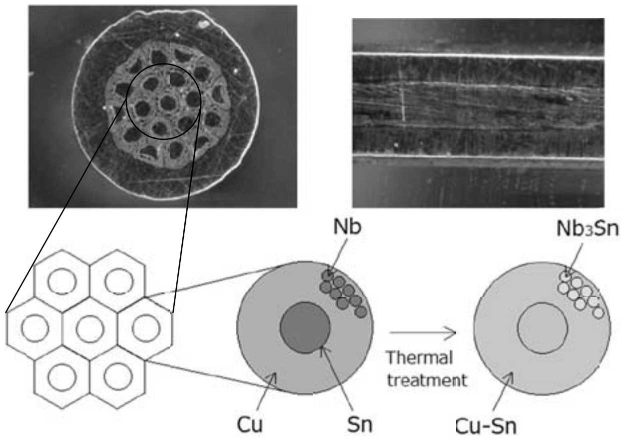
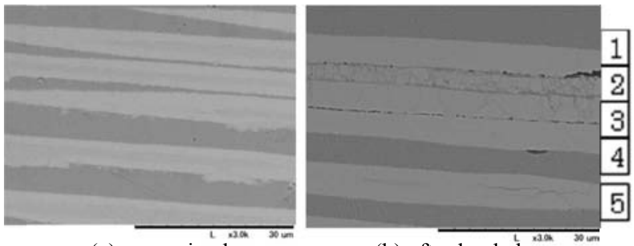


Fig.1 Cross section of internal diffusion process wire.



(a) as received (b) after loaded

Fig.2 SEM observations of longitudinal section of wires.

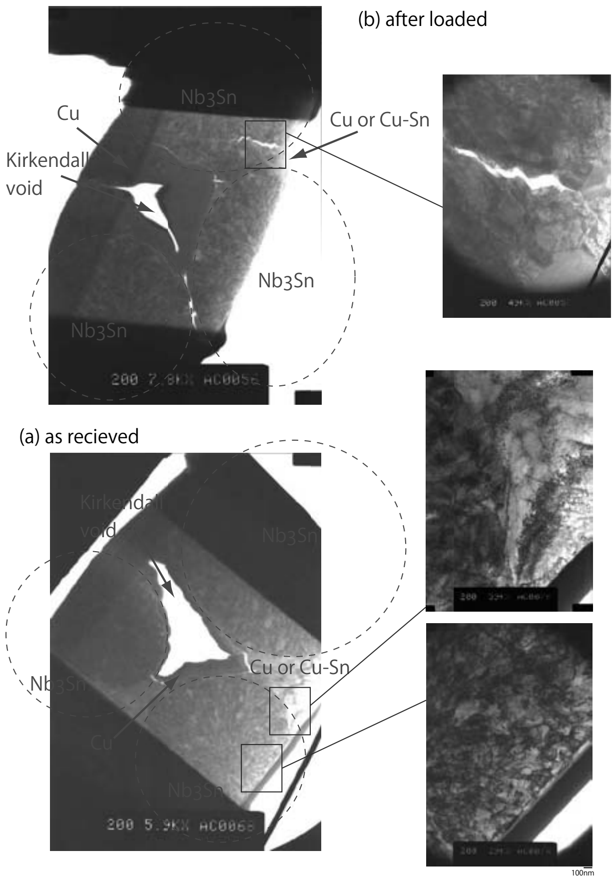


Fig.3 TEM observations of cross section of wires