Study on Defect Structure Evolution in SS 316LN under Combined Cyclic Loading by Diffraction Contrast Imaging in TEM

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The present study investigates the defect structure characteristics under different damage modes such as low cycle fatigue (LCF), creep-fatigue interaction (CF) and LCF-creep-HCF interaction at 923K in SS 316LN, a widely used structural material for reactor application [1]. The micro structural evolution after deformation has been studied using various methods of diffraction contrast imaging in TEM such as two-beam dynamical condition, bright field kinematical condition, and weak beam dark field condition.

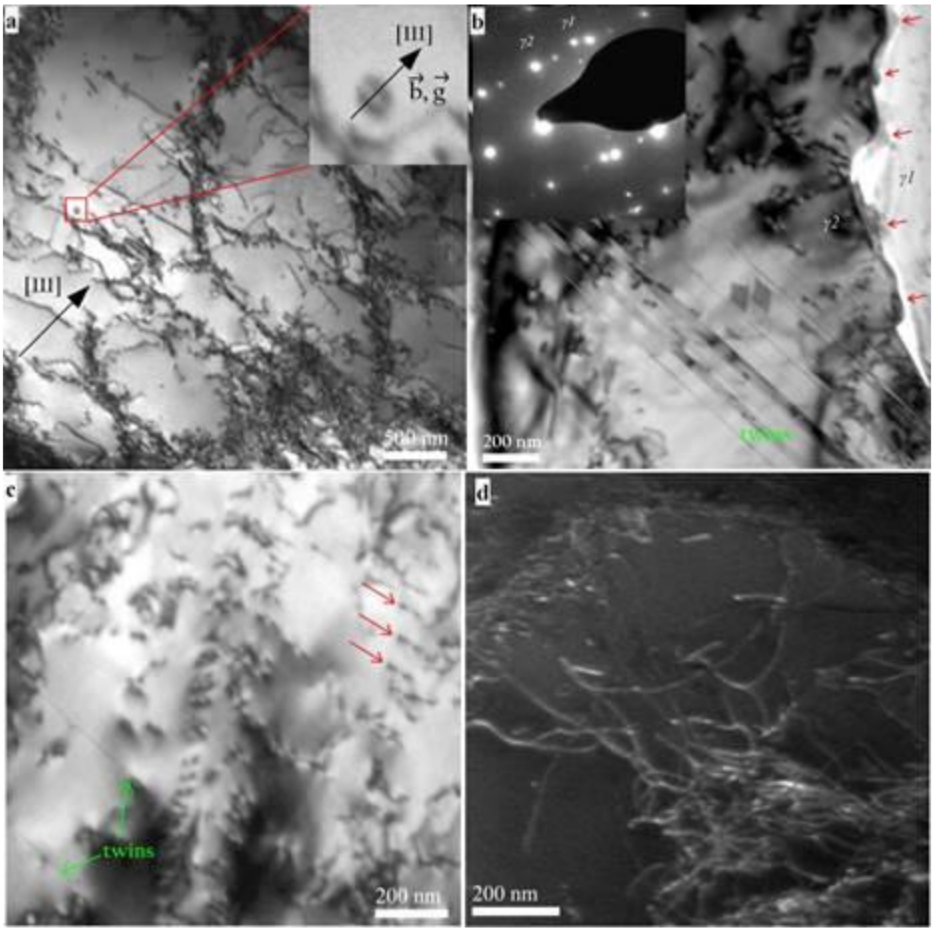

Fig. 1(a-d) Defect structures in SS 316LN subjected to LCF testing at 923K

The early stage of dislocation cell formation has been identified in the sample subjected to LCF (0.25% strain amplitude) under two-beam conditions using reflection g=111 (Fig. 1a). The lattice strain fields generated from free dislocations, tangled dislocations, and dislocation loops are distinguishable by amplitude contrast. The crystallographic direction and Burgers vector has identified for dislocation loops by the invisibility criterion |g.b|=0 [2] as illustrated in the inset of Fig. 1a. The bright field image in kinematical condition (Fig. 1b) discriminates the contrast of deformation twinning and $M_{23}C_6$-type grain boundary precipitates of 50 nm size (red arrow). Diffraction pattern analysis shows a cube-on-cube orientation relationship ($[111]_{\gamma}//[111]_{M23C6}$, $[002]_{\gamma}//[002]_{M23C6}$) between γ1 and $M_{23}C_6$, which suggests the coherency between the phases. The abundance of deformation twins on {111} plane is evident near to the grain boundaries. Fig. 1c manifests the slip planes at its early stage of piling up (red arrow) in persistent slip bands, and twin planes are the same, $(111)_{\gamma}$. Imaging under the weak beam dark field condition (Fig. 1d) has been effectively used to characterize the complex dislocation microstructure such as tangled dislocations which occur in high-damage regions randomly inside the cell structures, where each strand of lattice strain field including Shockley partials can be distinguished.

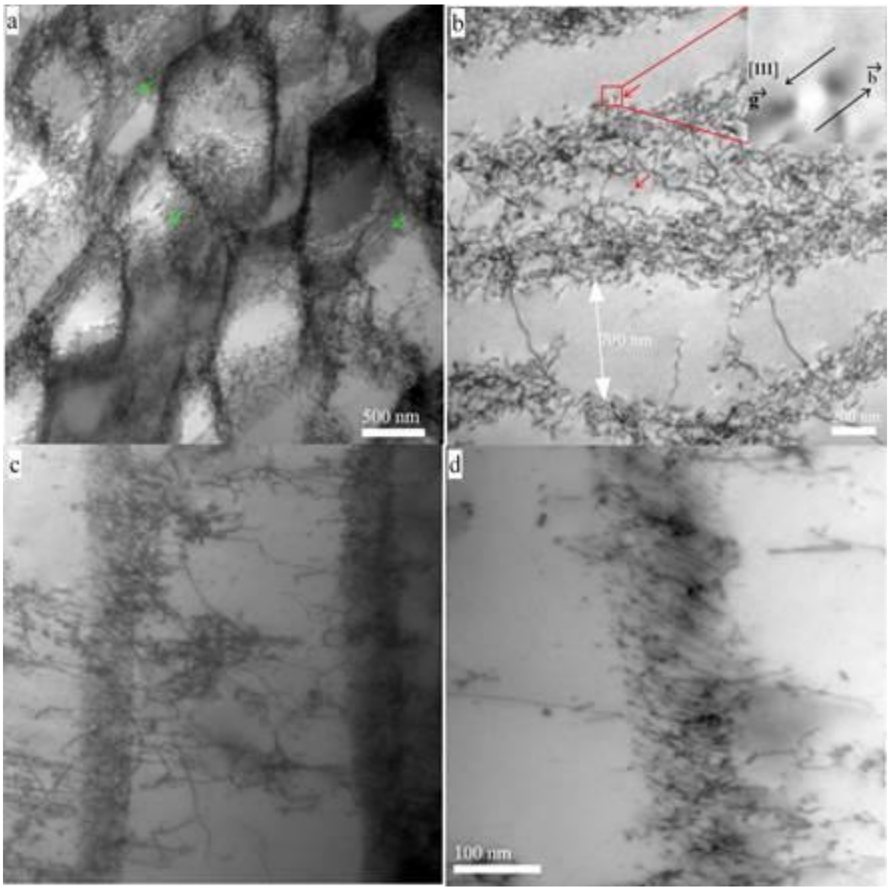

Fig. 2(a-d) Defect structures in SS 316LN subjected to LCF- Creep-HCF interaction at 923K

The dislocation cell has well-defined boundaries in steel that has undergone combined interaction of LCF-creep-HCF as shown in Fig. 2a. The dislocations tend to stack along the cell walls perpendicular to wall thickness (green arrows). The dislocation vein structure (Fig. 2b) occurs with the rough periodicity of ~700 nm which is interestingly similar to dislocation cell dimensions. In contrast to the dislocation stacks along the cell wall, accumulated and tangled dislocations have been observed in each band. The point defects (red arrows) are identified as the Frank edge-on loops, and by analyzing the contrast variation for different reflections the Burgers vector is determined as b= 1/3[$\bar{1}\bar{1}\bar{1}$]. The persistent slip bands (width ~ 50 to 250 nm) with multitudes of dislocation pile-ups (Fig. 2c) are prominent in samples subjected CF and LCF-creep-HCF testing. In contrast to LCF sample, the slips repeatedly occur in LCF-creep-HCF, and the distance between each slip is ~ 5-10 nm (Fig. 2d). The study proves the defect-microstructure is characteristic of each deformation condition.

References

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