Dislocation Dynamics Simulations of Persistent Slip Bands During Fatigue of FCC Metals

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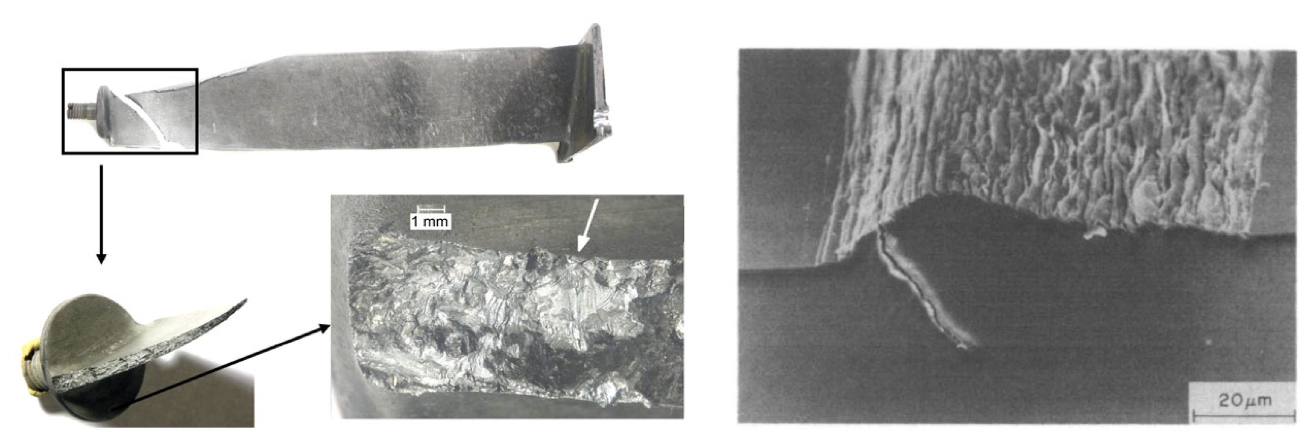
Motivation and Background

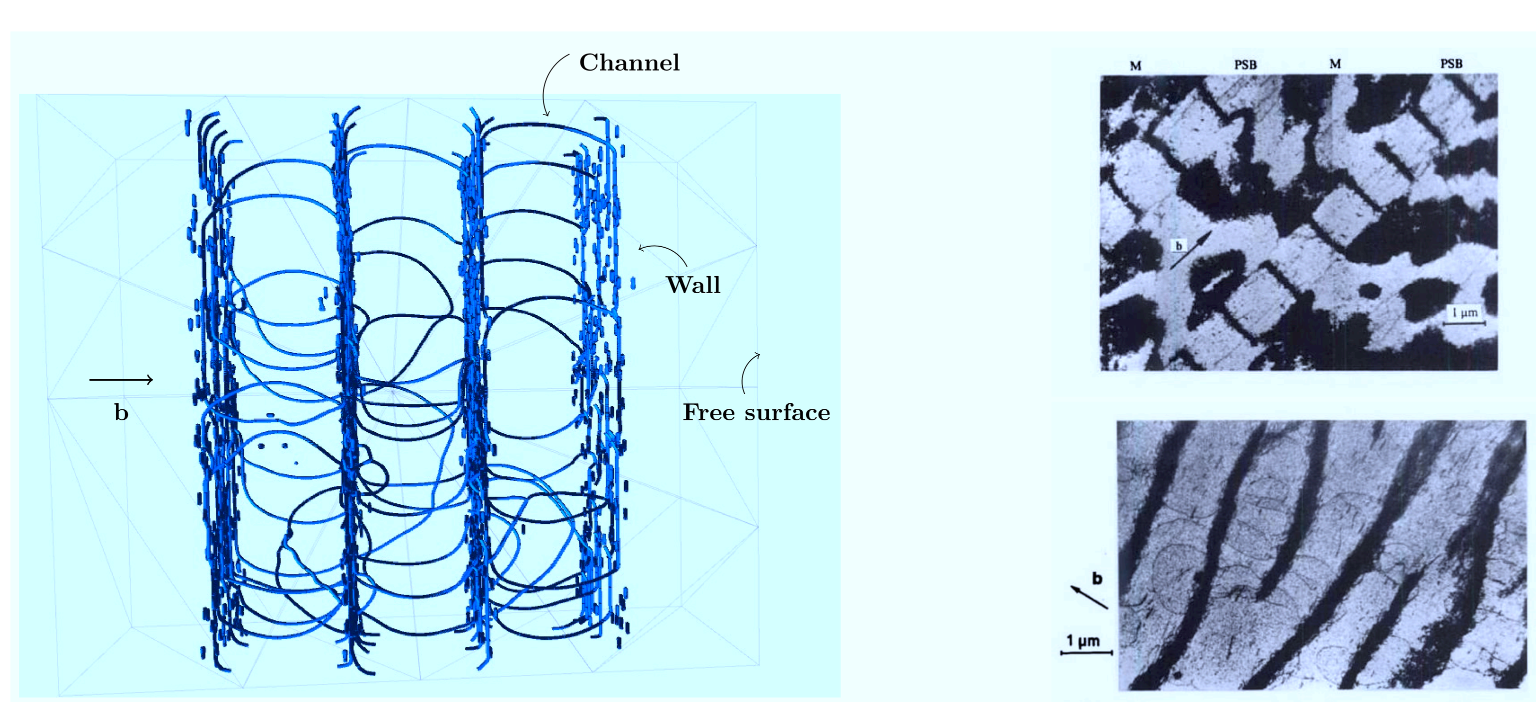
- The fatigue of an engineering structure is a multiple-stage process and originates from the initiation of micro cracks.
- Once they are nucleated, the propagation and accumulation of micro fatigue cracks can rapidly lead to the formation of macro-scale cracks and ultimately failure of the structure.
- Therefore, it is crucial to identify the dislocation mechanisms at micro-scale which lead to fatigue crack initiation.
- Experimental observations show that, in FCC materials, fatigue cracks start at the sites where persistent slip bands (PSBs) meet the free surfaces of their surrounding crystals.



(i) In-service failed vane blade in an aircraft engine. (Shanyavskiy 2014) (ii) A PSB with a fatigue crack after 60000 cycles at $\gamma_{pl} = 0.002$. (Hunsche 1986)

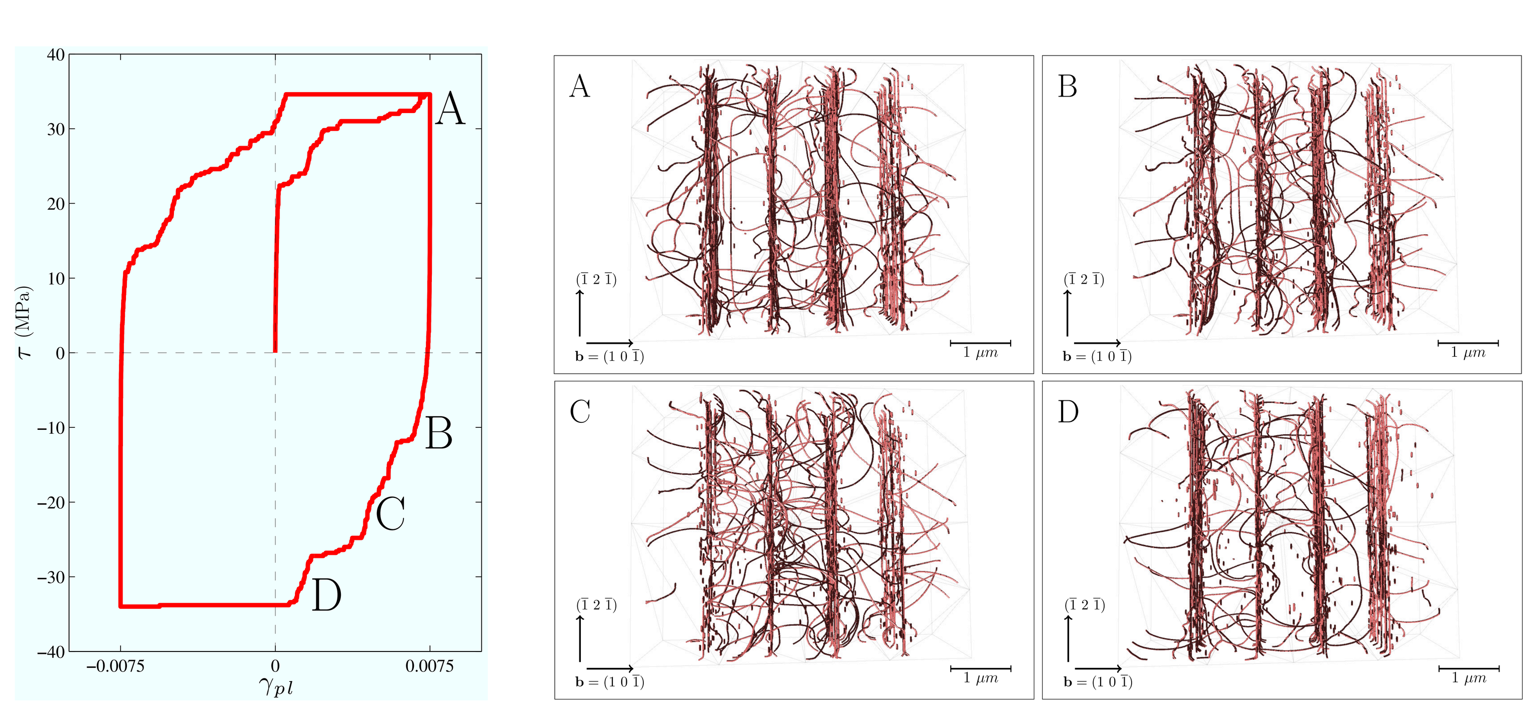
Model Summary

- A fully developed PSB, excluding the crystal bulk surrounding it, is taken into account.
- In each channel of the PSB, an initial random distribution of screw dislocations whose ends are pinned at the neighboring walls are chosen.
- The walls of the PSB are initially designed with a random distribution of dipolar loops with various heights.
- In order to reduce the computational cost of the simulations, the walls are assumed to be partly formed of sessile virtual dipolar loops which are not involved in local short-range dislocation activities but only provide long-range elastic stress field.

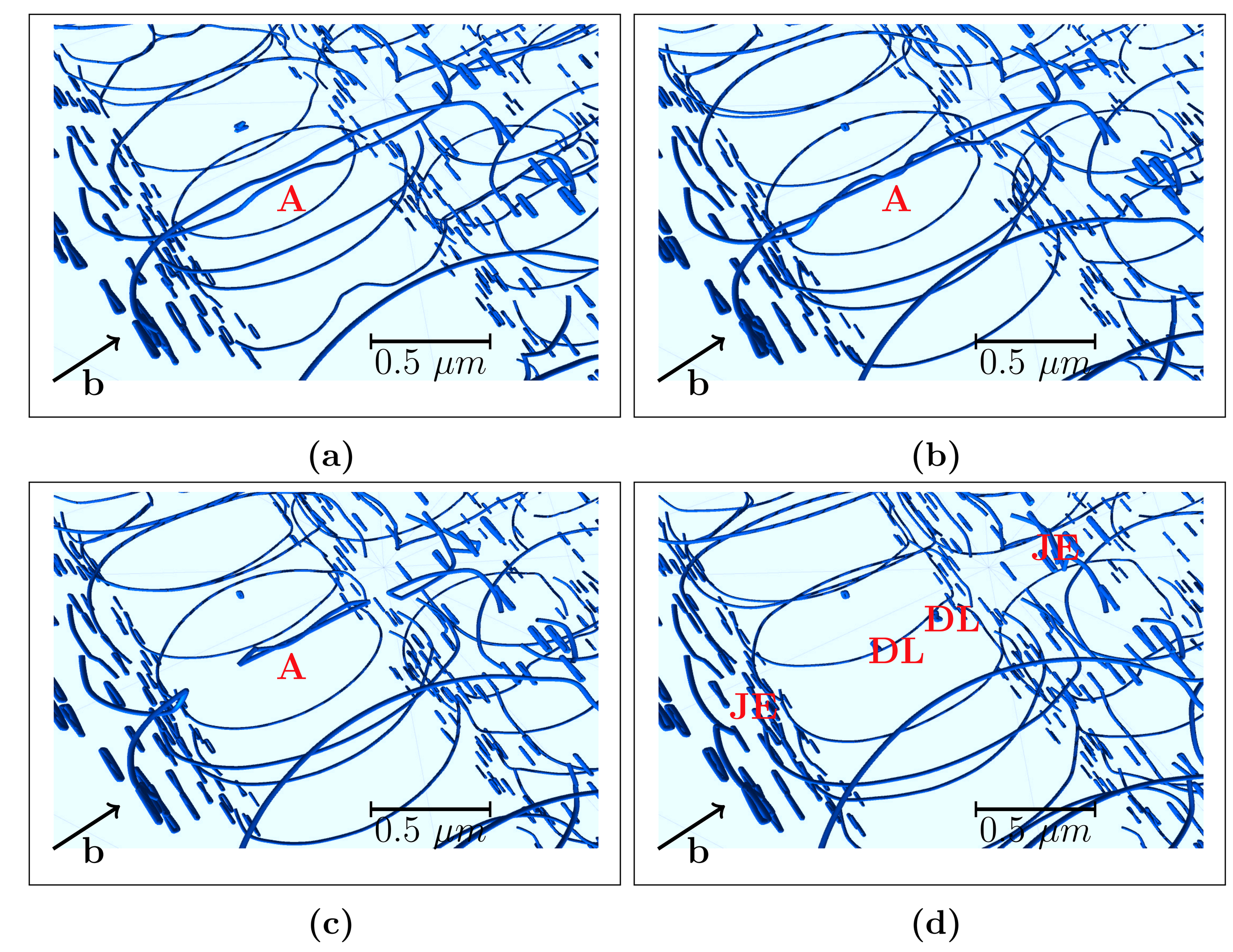


(i) Dislocation dynamics simulation of PSB. (ii) TEM views of PSBs in fatigued copper. (Mughrabi 1979)

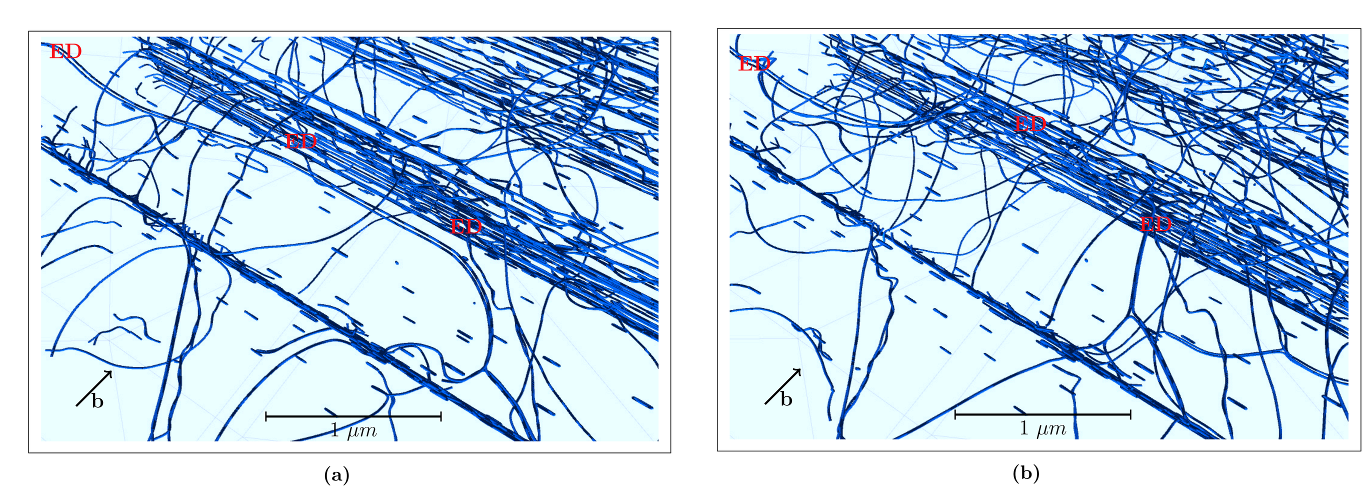
Stress-Strain Response and Microstructure Evolution at $\gamma_{pl}^{local} = 0.0075$



Microstructure Mechanisms



The process of the annihilation (A) of two screw dislocations by a Tetelman-like mechanism. Dipolar loops (DL) and jogged edge segments (JE) are produced as by-products.



The formation and piling-up of an elongated edge dipole (ED).

Conclusions

- The model have been validated by comparing the simulation results with the published data in literature, for both the stress-strain behavior and the corresponding dislocation microstructures. The persistent slip band model has proved to be an important tool in analyzing the cyclic plasticity of FCC crystals
- A strong link exists between the rate of edge dislocation penetration through walls and the instability of PSBs.

Future Research

- Further studies should focus on determining the evolution of surface roughness and thus fatigue cracks.
- The annihilation of edge dipoles and the generation of point defects are neglected in our simulations. A future study including these two factors would be very interesting.

References

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