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Mechanism and Analysis of Orange Peel Formation on Bent Thin-Walled Copper Tubes

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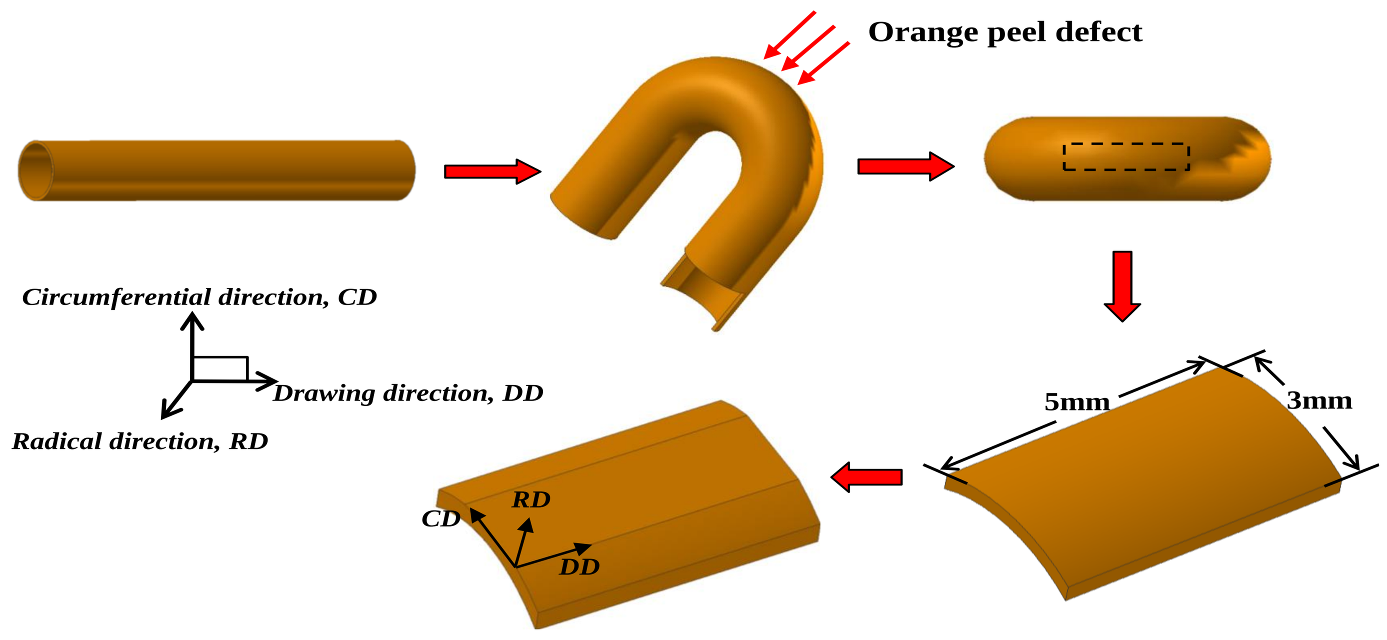
INTRODUCTION & AIM

With the growing demand for precision in thin-walled copper tubes used in refrigeration, aerospace, and electronics, surface quality control has become crucial in plastic processing. Thin-walled copper tubes, known for their excellent thermal conductivity and formability, often undergo bending to connect hot and cold ends. However, excessive bending angles or small bending radii can lead to orange peel defects. These surface defects negatively impact the heat dissipation capability, corrosion resistance, and aesthetic quality of the heat pipe. Therefore, addressing orange peel defects in the bending process of thin-walled copper tubes is essential for improving product performance.

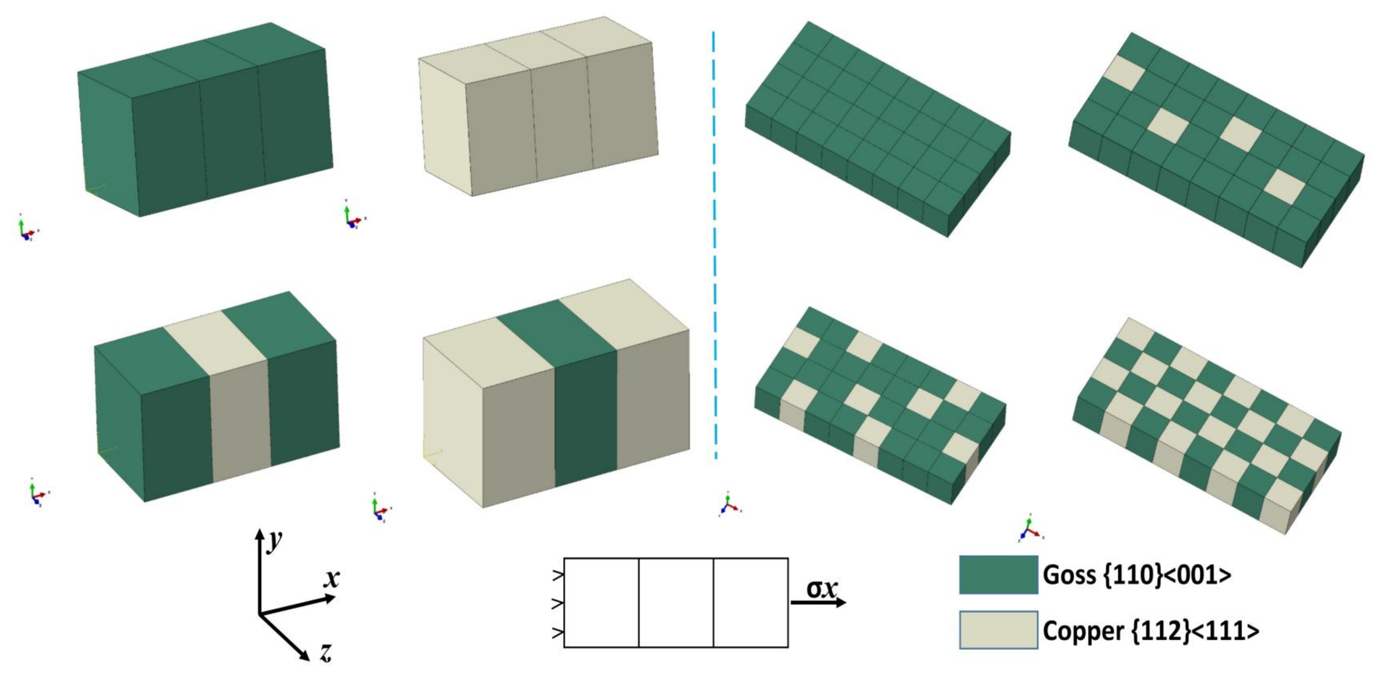
This study compares tube samples with and without orange peel defects by analyzing their macro-surface morphology and microstructural evolution before and after bending. The crystal plasticity finite element model (CPFEM) was developed to explore the correlation between crystallographic orientation and surface defects. Finally, the multi-scale model of the tube bending process is developed by integrating the macroscopic finite element method (FEM) with the visco-plastic self-consistent (VPSC) approach to simulate and analyze the formation of orange peel defects on the outer wall of the tube at the bending site.

METHOD

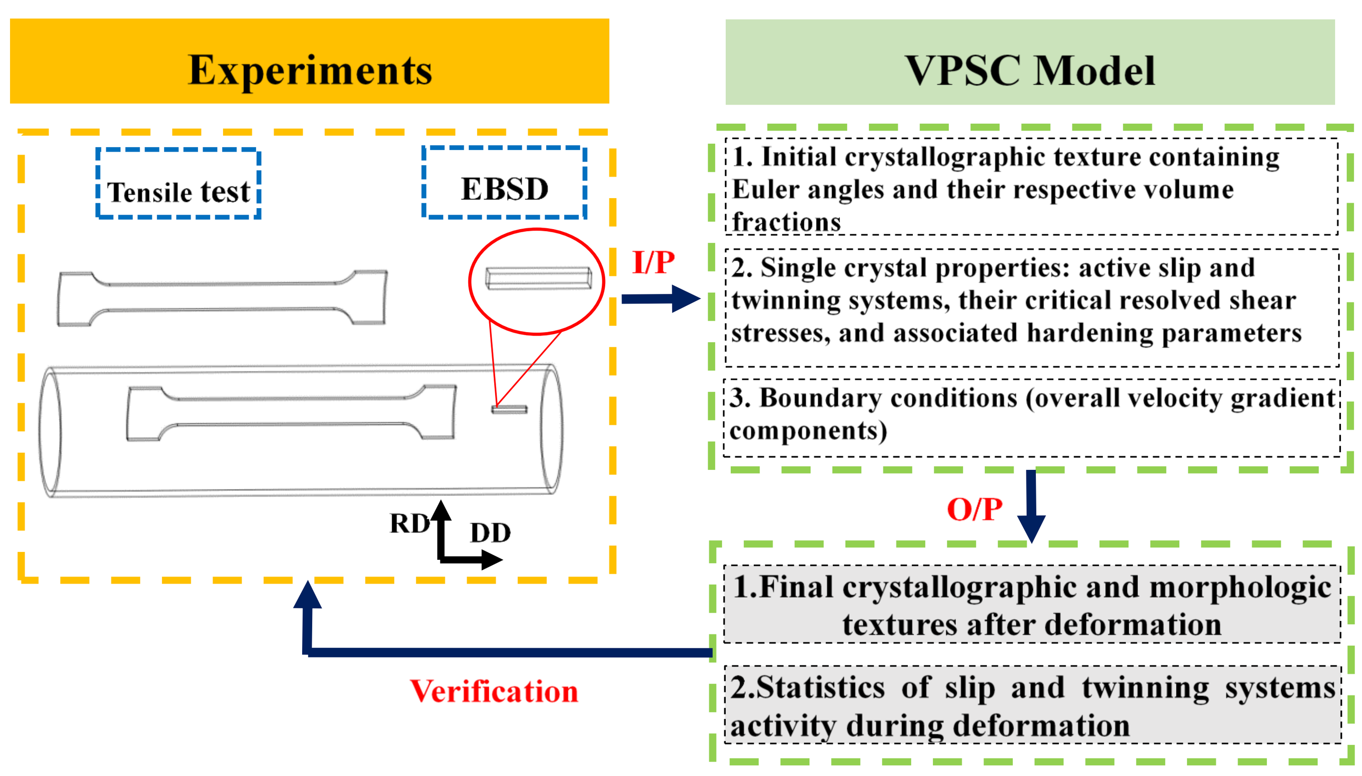
- **Sampling and EBSD and SEM observation for both types of copper tubes**



- **CPFEM modeling to discuss the effect of texture type and content on orange peel defects**



- **VPSC modeling to investigate the mechanism of orange peel formation**



RESULTS

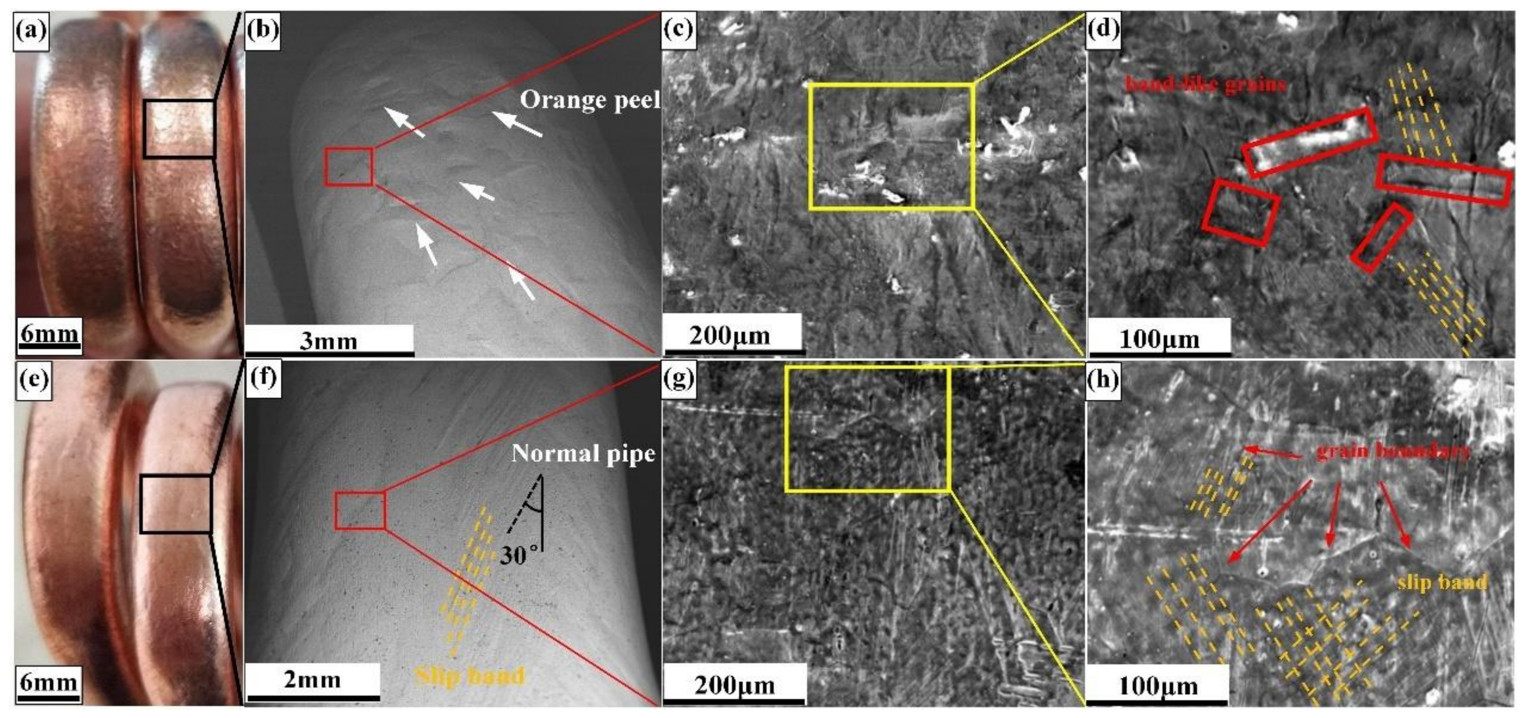


Fig. 1 Visual observation and SEM observations with (a)-(d) and without (e)-(h) orange peel tubes

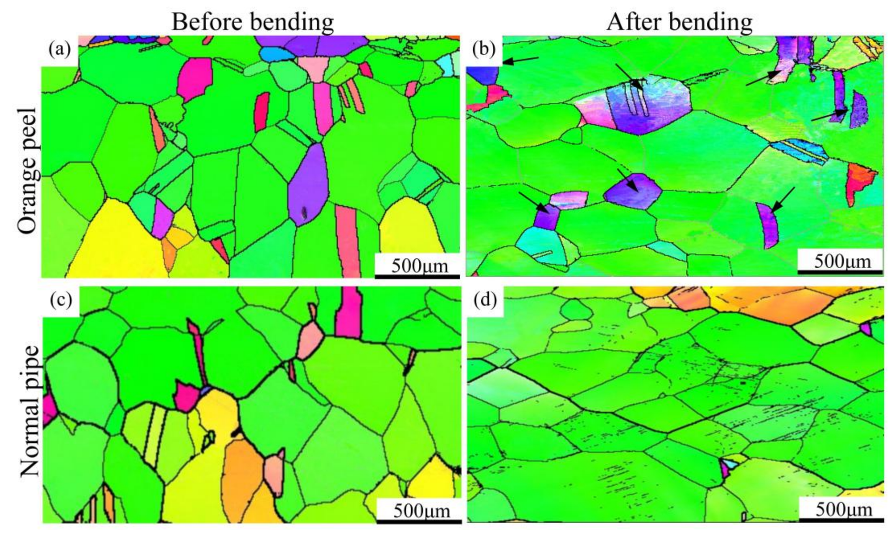


Fig. 2 Orientation distribution of tubes with and without orange peel defects before and after bending

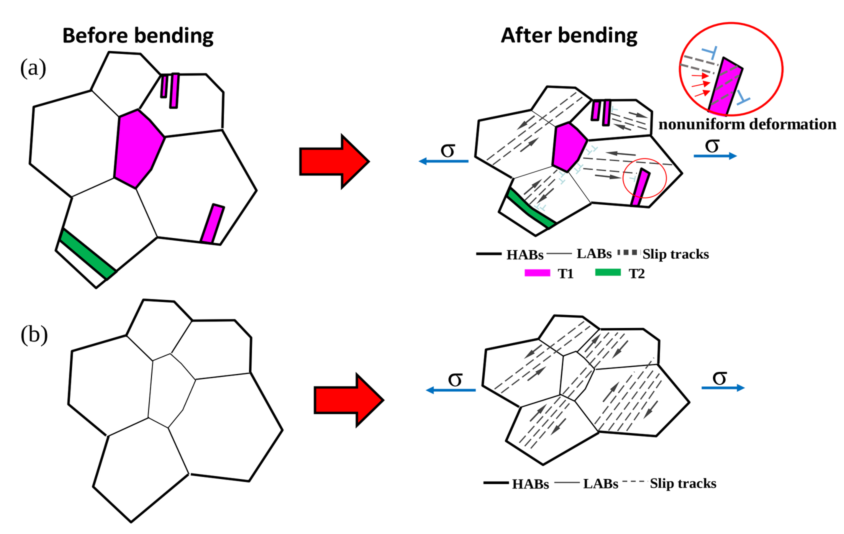


Fig. 3 Schematic diagram of orange peel formation mechanism on bent tube

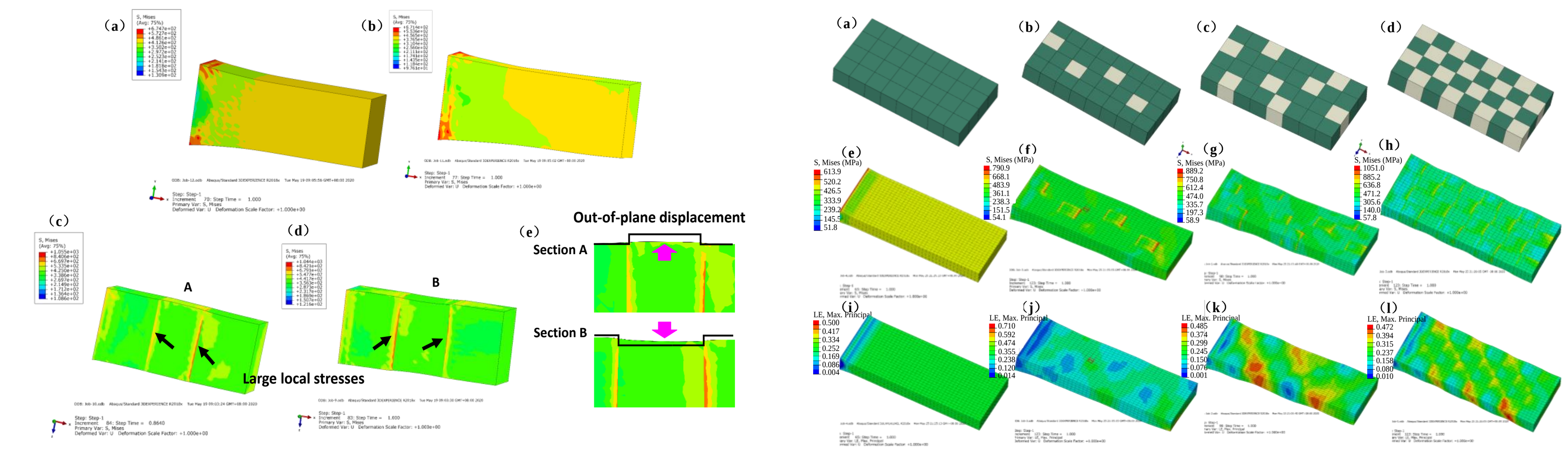


Fig. 4 Simulation results with different neighboring grain orientations and texture contents

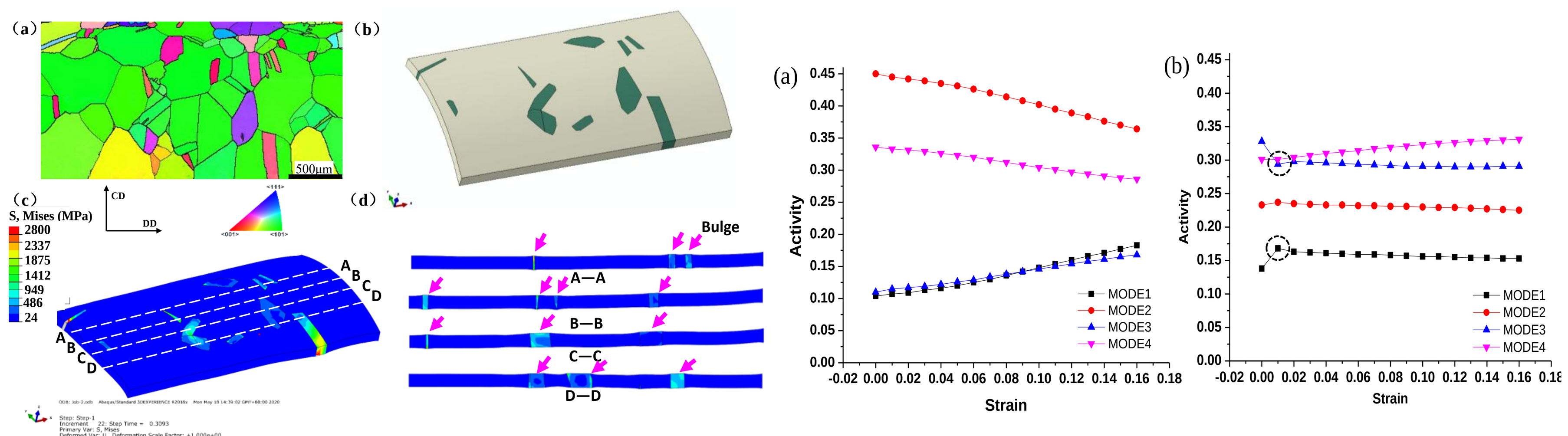


Fig. 5 RVE model and simulation results of surface morphology of orange peel tubes

CONCLUSION

- **After high-temperature sintering, small blocky and strip-like grains with orientations significantly harder than the matrix are observed in tubes with orange peel defects, while such abnormal grains are absent in defect-free tubes. These hard-oriented grains weaken and disperse the recrystallization texture. Their presence disrupts deformation coordination within the tube wall, contributing to the formation of orange peel defects.**
- **CPFEM results reveal that plastic deformation under uniaxial tension primarily occurs in the soft-oriented matrix, while the hard-oriented grains resist deformation, leading to localized strain accumulation. As the fraction of hard-oriented grains increases, surface roughness intensifies.**
- **VPSC simulation results indicate that the number of activated slip variants differs between tubes with and without orange peel defects. The defected tubes exhibit fewer slip variants and encounter greater resistance during deformation.**