Observation and simulation of the Portevin-Le Chatelier effect at the grain scale in a polycristalline Nickel based superalloy

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Abstract

The Portevin-Le Chatelier (PLC) effect is a plastic instability phenomenon characterised by a fluctuating evolution of the flow stress, the formation of plastic strain rate localisation bands within the specimen, and a negative strain rate sensitivity during tensile tests. These manifestations occur within specific temperature and strain rate ranges due to dynamic strain ageing (DSA), which arise from the dynamic interaction between mobile dislocations and diffusing solute atoms. The microscopic origin of this effect and its macroscopic consequences are now well understood, and models are available to simulate the jerky flow using finite element simulations (1), (2). Nevertheless, the investigation of the PLC effect at an intermediate scale, such as the polycrystalline aggregate, remains less explored. In particular the emergence of plastic localisation in the grains and the impact of the PLC effect on the local mechanical behaviour require further investigation. Consequently, the present study aims to provide both experimental observations and modelling of the PLC effect in a nickel based superalloy, in this case an Inconel 718, within the framework of crystal plasticity.
In-situ scanning electron microscopy (SEM) experiments were conducted to observe the PLC effect in polycrystalline aggregates. These experiments capture the intermittency of plastic deformation, along with pronounced heterogeneities and strain localisation patterns at this scale. These observations highlight the critical role of microstructural interactions in the emergence of the PLC effect. To complement these experimental insights, a finite element crystal plasticity model was built to simulate the mechanical behaviour of the polycrystalline aggregates. This model builds on the classical crystal plasticity framework by incorporating the Kubin-Estrin-McCormick (KEMC) model, which accounts for the influence of dynamic strain ageing in the isotropic hardening rule (3). The simulations reproduce key features of the PLC effect, such as deformation intermittency and localised plasticity.

By combining experiments with advanced modeling, this work offers new insights into the mechanisms driving the PLC effect and provides valuable tools for understanding its implications on material behavior.

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References

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