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Review on cellular automata simulations of microstructure evolution during metal forming process: Grain coarsening, recrystallization and phase transformation

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Cellular automata (CA) algorithm has become an effective tool to simulate microstructure evolution. This paper presents a review on CA modeling of microstructural evolution, such as grain coarsening, recrystallization and phase transformation during metal forming process which significantly affects mechanical properties of final products. CA modeling of grain boundary motion is illustrated and several aspects of recrystallization are described, e.g. nucleation and growth, the development of static and dynamic recrystallization. For phase transformation, attention is paid to such key factors as solute element diffusion and change of systemic chemical free energy. In view of the reviewed works, several open questions in the field of further development of CA simulation are put forward and recommendations to them are given.

cellular automata algorithm, grain coarsening, recrystallization, phase transformation

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1 Introduction

It is well known that microstructure of metallic materials, such as morphology, grain size, phase fraction and their spatial distribution, largely affects the mechanical and functional properties of final products [1, 2]. Accordingly, an investigation into microstructure evolution has drawn substantial attention from both the industrial and scientific communities. For the past decades, many researchers have carried out both theoretical [3–5] and phenomenological modeling [6–8] on this subject. Using these models, the kinetics of microstructural evolution could be analyzed. However, phenomenological models are too simple to reasonably describe the physical process, and the theoretical models include complicated mathematical calculation and a lot of assumptions. Thus, neither of them are the exact one for suitable use in practice.

Therefore, various numerical simulation techniques such as vertex models [9–12], Potts-Monte Carlo models (MC) [13–16], phase field models [17, 18] and cellular automaton models (CA) [19–22] are gradually used to carry out numerical simulation of microstructure evolution on mesoscale in recent years. Besides accurately predicting the general average microstructure properties, these models could visibly reproduce the process of microstructural evolution. Comparing with alternative modeling methods, CA model is more feasible to characterize evolution kinetics and topology features due to its intrinsic advantages of ready calibration to time and length scale. The respective characteristics of these numerical simulation methods on mesoscale will be discussed in detail in Section 2.2.

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