Materials Science & Engineering A 647 (2015) 191–200

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

A new unified approach for modeling recrystallization during hot rolling of steel

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ARTICLE INFO

Article history:
Received 30 March 2015
Received in revised form
26 August 2015
Accepted 27 August 2015
Available online 29 August 2015

Keywords:
Recrystallization
Model
Simulation
Hot rolling
Microstructure
Steel

ABSTRACT

Recrystallization during hot rolling of steel and the developing austenite grain size play an essential role for the phase transformation during cooling and the resulting mechanical properties. Thus, many models for recrystallization were developed in the past decades. While constitutive models are still state-of-the-art for online process control, mesoscale models with a spatial representation of the microstructure can provide better predictive capabilities at the cost of long computation times. To fill this gap a new approach based on modeling the interaction of an ensemble of multiple grains is proposed. Simulation results with this new model are in good agreement with results from experiments with a heat treatable 42CrMo4 steel. It is shown that the model can also describe the behavior under transient conditions known from experimental investigations and cellular automata models.

1. Introduction

The microstructure evolution during hot rolling of steel is of great interest for its industrial production and has therefore been subject of research in the past decades. Recrystallization during and after hot rolling is one of the mechanisms that can be used for grain refinement [1,2]. The resulting microstructure after hot rolling is also important for the following phase transformation during cooling having a significant influence on the mechanical properties of hot rolled products. In consequence, controlling the recrystallization is one opportunity for controlling the mechanical properties and in turn gives room for saving expensive alloying elements. Therefore models with good predictive capabilities and low computation times are demanded.

1.1. Models for recrystallization

Since dynamic recrystallization had been observed by Greenwood and Worner [3], many theories and models for its description have been developed. These models differ in terms of complexity, characteristic length scale, practical usability and the considered materials. In the following major approaches for modeling recrystallization are described and their feasibility for process control application is discussed. The various types of approaches are outlined in Fig. 1. Results from mesoscale approaches show that there is a good understanding of the mechanism leading to the observed phenomena during deformation related to recrystallization while short computation times can be achieved with constitutive models.

1.1.1. Constitutive models

Constitutive models provide a simple way of describing the microstructure evolution mostly by closed form equations, which make it possible to use them even in simple spread sheet applications. Sellars and Whiteman [4] proposed such a model designed for the application of the simulation of the microstructure evolution during hot rolling that built the starting point for many other models developed by several groups [5–12]. These models use the temperature T, the strain ε and strain rate $\dot{\varepsilon}$ of each deformation step, the initial average grain size d_0 and the time t after the prior deformation as input parameters. The output parameters are the recrystallized volume fraction X and the average austenite grain size d after deformation. Constitutive microstructure evolution models distinguish between different recrystallization phenomena like dynamic, metadynamic and static recrystallization (*DRX*, *MDRX* and *SRX)* and grain growth that are modeled separately by closed form formulations based on physical considerations. Each of these equations contains many material parameters

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http://dx.doi.org/10.1016/j.msea.2015.08.085
0921-5093/

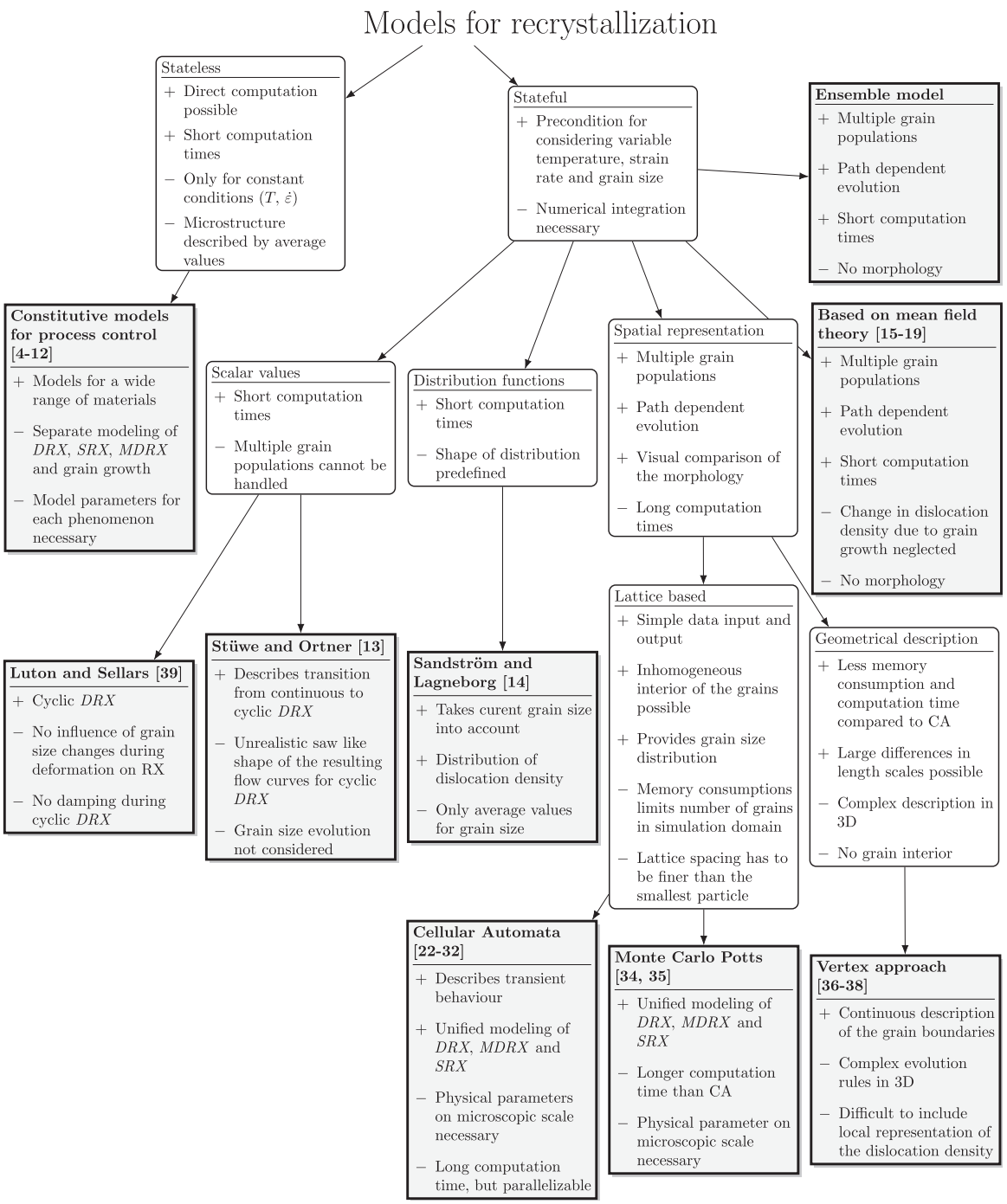

Fig. 1. Hierarchical overview of the features and constraints of different model approaches for recrystallization. The models (highlighted with a thick border) are divided into several branches based on the underlying modeling techniques.

making them easily adjustable to experimental data but also demanding in terms of the number of experiments required. Since only average values are considered it is not possible to track multiple volume fractions that have recrystallized at different time steps. Although such models cannot describe the influence of the previous processing path due to the lack of inner state variables, they show good agreement with experimental results at steady state conditions, whereas cyclic recrystallization and transient oscillations cannot be described.

1.1.2. Inner state variable models

Since the evolution of microstructure depends on its current state, models using inner state variables have been introduced. Stüwe and Ortner [13] suggest a model for *DRX* that describes the recrystallized volume fraction and the resulting flow stress during deformation depending on strain rate and temperature based on the evolution of the dislocation density. Sandström and Lagneborg [14] propose an extended approach featuring a rather complex description of the evolution of the density distribution of dislocations on and between subgrain walls. Considering the change of the grain size and its effect on the nucleation rate it is able to describe the damped oscillations in flow curves at low strain rates. In comparison with data from experiments with nickel the calculated peak strain at high strain rates is too high. This is explained by not taking into account the strain rate dependency of the mean free path and the dislocation mobility.