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# Study on the dynamic recrystallization mechanism during pre-stress dry grinding

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ABSTRACT

Controlling grain size plays an important role in optimizing hot-working process and achieving the desirable mechanical properties. This paper focuses on a series of pre-stress dry grinding experiments to investigate the microstructure evolution of AISI 1045 steel considering the dynamic recrystallization (DRX) behavior. In order to reveal the effect mechanisms of grinding parameters and pre-stress on microstructural evolution, the simulation model is built. The model considers the effect of deformation temperature, grain size and pre-stress on DRX. By multiple linear regression analysis of the flow stress-strain datas, the DRX model parameters and volume fraction are determined. Than the nucleation mechanism of DRX is investigated by observing surface microstructure. The predicted average grain size and volume fraction of the DRX grains are in good agreement with the experimental ones. The results indicate that the pre-stress dry grinding technology can promote DRX nucleation, refine grain size and decrease workpiece surface roughness.



## 1. Introduction

Grinding technology has been widely applied in engineering because it can generate high accuracy surface. In grinding, heat generates in the contact zone between grinding wheel and workpiece. Brinksmeier and Brockhoff [1] proposed to use the great heat generated in the contact zone to produce hardening layer of workpieces. The new technique was called Grind- Hardening (GH). GH technology combined traditional grinding and surface hardening, but in the process, the great heat will make the surface topography produce distortion and then impact on the surface roughness [2].

Pre-stress dry grinding as a new manufacturing technology combines pre-stress grinding and surface hardening [3]. This processing technology can improve the hardness of workpiece surface and reduce the surface roughness [4]. However, the relationship between pre-stress and surface topography is researched almost by experimental observation [5], the effect mechanism is seldom researched.

Research suggests that the dynamic recrystallization (DRX) behavior can improve the plastic deformation ability of workpiece, reduce the work-hardening and refine grains. Therefore, the surface roughness will reduce with DRX process continues, while surface roughness has a major impact on workpiece properties (friction and wear, resistance to fatigue, cooperation, et al.). Therefore, it is significative to investigate the DRX behavior of materials and make it visible during pre-stress dry grinding process under various conditions. Poliak and Jonas [6] proposed DRX behavior usually occurs during hot deformation. Majority experiments were carried out to investigate the DRX behavior and microstructure evolution during the forging process. It is characterized by clear nucleation and growth stages, with preferential locations of nuclei at the initial grain boundaries. Wang et al. [7] reported that the DRX behavior generally occurs in low strain rate and high temperature metals. Pre-stress dry grinding technology provides the conditions for DRX behavior owing to its unique processing method.

When the metallic material surface undergoes various thermal and mechanical stresses in grinding, it's surface performance and final microstructure is strongly related with microstructure evolution [8]. Matsumoto and Velay [9] proposed DRX behavior is one of the most important microstructural evolution mechanisms. Development in computer technology and numerical simulation technology provides a new platform for metal forming technology. Simulation method with embedding DRX model would provide a concisely visual interface, which can present the dynamic characteristics of the DRX evolution during hot deformation process [10]. Many scholars have taken up extensive theoretical and experimental researches in this field. Over the past few decades, microstructure evolution models based on Johnson-Mehl-Avrami-Kolmogorov (JMAK) formulation [11] has been developed. These models realized microstructural prediction during hot-working.

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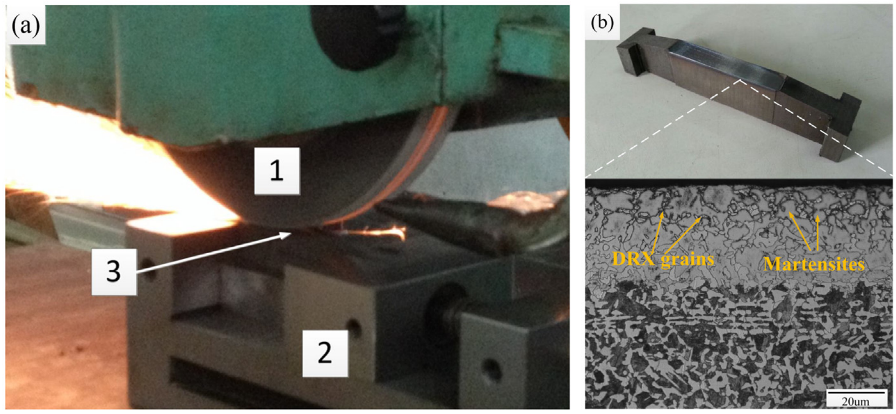


**Fig. 1.** (a) Grinding process and (b) workpiece and its microstructure after pre-stress dry grinding.

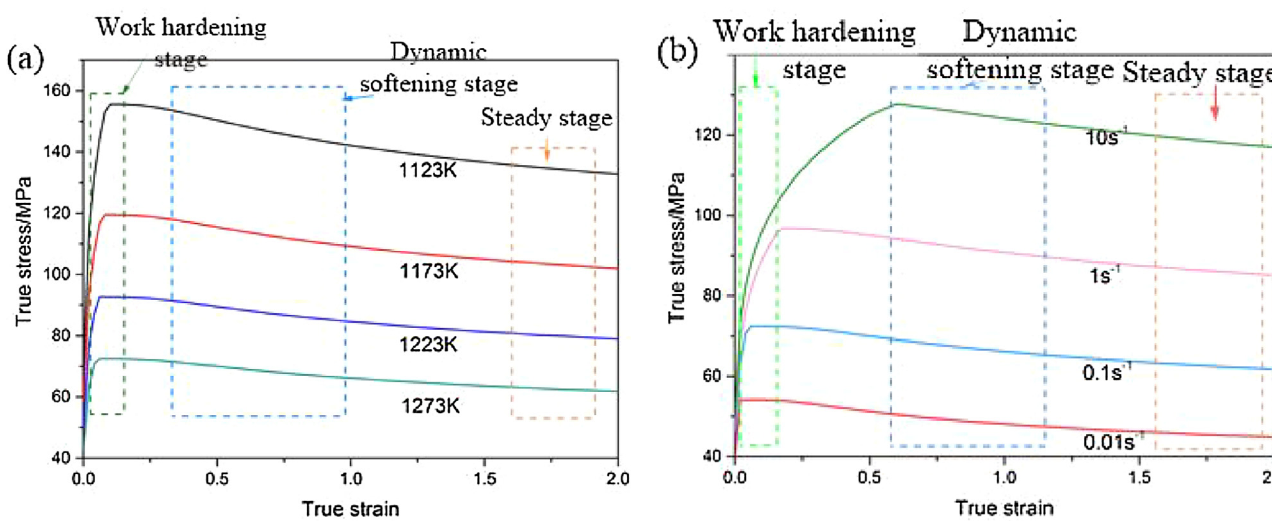


**Fig. 2.** The true stress-strain curves under different temperatures and strain rates.

However, the effect of strain on DRX behavior hasn't been considered in these models. Ding et al. [12] adopted the Monte Carlo method to simulate the microstructural evolution. However, due to the limitations of Monte Carlo method, it can't present the dynamic characteristics of grain growth. Recently, one approach of adopting Cellular automaton (CA) method to simulate microstructural evolution in material forming has attracted widely attention. Wu et al. [13] adopted CA method to simulate the recrystallization microstructure in the metal cooling process. Li et al. [14] considered the effect of different strain rates on microstructural evolution in Ni-based superalloy.

The objective of this paper is to develop a simple model for DRX behavior based on DEFORM-3D platform and CA algorithm. Then the theoretical model is verified in a series of experiments. Moreover, the DRX mechanism is investigated through observing the microstructure.

## 2. Experiment

### 2.1. Experiment conditions

The material used in this study is AISI 1045 steel, and its chemical composition (wt.%) is 0.45C–0.20Si-0.50Mn-0.30P-0.30S-0.2Cr-0.25Ni-0.25Cu-(bal.) Fe. The machining size of specimen is $50 \times 22 \times 10$ mm ($l \times b \times h$). Pre-stress dry grinding experiments are conducted on a M7120A surface-grinding flat grinder. The grinding wheel is vitrified bond white alumina wheel with abrasive grain of F46.

### 2.2. Experimental process

Pre-stress dry grinding experiments are carried out to investigate the DRX behavior under different grinding conditions, the detail parameters are listed in Table 1. First, the workpiece was put into a special clamp. Before grinding, applying torque by pre-stress wrench. Then, the pre-stress fixed on the workpiece both ends by pulling slide block. The pre-stress value can be control by the applied torque. The specimens are applied different pre-stress (0MPa, 33.3MPa, 66.7MPa, 100MPa). The objective of applying pre-stress is to produce a strain on the surface of specimens during the experiments. In order to study the effect of temperature on DRX behavior, the grinding depths are different. The temperatures ranging from 800 °C to 1200 °C and the strain rate is less than $10^{-2}$ s$^{-1}$ during grinding process. The experimental set-up and results are shown in Fig. 1. Matrix and strengthened layer can be observed, and the DRX grains appear around the grains boundary.