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Effects of thickness reduction on recrystallization process of warm-rolled pure tungsten plates at 1350 °C

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HIGHLIGHTS

- The effects of thickness reduction ratio on the evolution of hardness and microstructure of warm rolled pure tungsten at 1350° were investigated.
- A Johnson-Mehl-Avrami-Kolmogorov (JMAK) model was selected to describe the hardness degradation process during the heat treatment process.
- The geometry and distribution of fully recrystallized grains were discussed.
- The higher thickness reduction leads faster recrystallization process and smaller grains with smaller aspect ratio.

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ABSTRACT

Investigations are conducted of the recrystallization behavior of pure tungsten through different thickness reductions by isothermal annealing at 1350 °C. Concise description is made of the recrystallization kinetics by the Johnson-Mehl-Avrami-Kolmogorov (JMAK) model in combination with hardness test results. The rate of the recrystallization process increases with the deformation ratio. For further investigations, three boundary maps of tungsten plates which are of different thickness reductions by rolling and in full recrystallization are obtained, each covering an area of 1.15×1.05 mm^2 on the transversal section comprising the rolling direction (RD) and the normal direction (ND). The average grain size and its distribution of pure tungsten can be easily calculated, and hence the grain aspect ratios of pure tungsten.

1. Introduction

Nowadays, the fusion power reactor is drawing enormous attention as a future source of energy. However, it demands the availability of plasma facing materials that can withstand extreme conditions of temperature, irradiation and thermal stress. Pure tungsten is the most promising candidate for the first wall material and the diverter components in fusion reactors, which will be subjected to high heat peak loads up to 10–20 MW/m^2 and temperature gradients [1], due to its high melting point, high strength at high temperatures, good thermal conductivity, low thermal expansion coefficient, high sputtering threshold energy and limited activation under neutron irradiation [2,3]. Pure tungsten is generally manufactured through different technologies, including powder metallurgy and plastic deformation process [4]. In terms of physical metallurgy, plastic deformation leads to the increase of the internal stored energy [5]. At high temperatures, recovery, recrystallization and grain growth will occur in deformed tungsten. These microstructural changes will cause degradation of the material properties, such as a loss in mechanical strength, or even embrittlement, as is the most critical.

S.N. Mathaudhu studied the microstructural evolution and recrystallization mechanism of coarse grained tungsten during annealing after equiaxial angular extrusion [6]. A. Vorhauer studied the microstructural evolution and thermal stability of tungsten-based materials afetr large plastic deformation. SEM and BSM were used to study the microstructure evolution and crystal size dis-

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tribution [7]. Alfonso, A. characterized the activation energy of pure tungsten during recrystallization by isothermal annealing and hardness degradation experiments and predicted the service life of pure tungsten at high temperatures through Arrhennius relationship, and established the kinetics of recrystallization model [8].

The present work investigates the effects of thickness reduction on the recrystallization behavior of pure tungsten at 1350 °C. The changes in the mechanical properties during annealing are quantified by Vickers hardness measurements. The changes of hardness and volume fraction of recrystallization are described by a Johnson-Mehl-Avrami-Kolmogorov model.

2. Materials and methods

Three warm-rolled pure tungsten plates with 50%, 67% and 90% (subsequently referred to as W50, W67 and W90) thickness reductions were received from Beijing Tianlong tungsten Technology Co. Ltd. These plates were cut off from the same sintered billet to ensure the same initial sintered microstructures. Small specimens of $6 \times 7 \times 8\ mm^3$ were cut off from the plates by wire-cut electrical-discharge machining. All samples were isothermally annealed for various durations of time at 1350 °C. Prior to heat treatment, the specimens had been placed in an evacuated and sealed quartz tube to avoid oxidation.

The hardness of the samples was measured with a load of 200 g for 10 s on the RD (Rolling Direction) × ND (Normal Direction or thickness direction) plane to evaluate the extent of recrystallization. In order to determine the hardness value, 10 measurements were carried out to obtain an average value for each sample. The reported hardness values $HV_{0.2} \pm \Delta HV_{0.2}$ are averages over 10 indents with the standard deviation $\Delta HV_{0.2}$ of the average, as is represented by error bars in the graphs below. Prior to hardness tests, the examined surfaces were prepared metallographically by subsequent mechanical grinding and polishing with SiC papers (1000 # in the final step) and polishing pastes, respectively. For the optical microscopic structure inspection, samples were etched with boiling 3% H_2O_2 aqueous solution. Optical micrographs were obtained under polarized light to examine the RD × ND plane of the specimens.

3. Results and discussion

Generally, the kinetics of the softening process during the annealing process can be categorized into three main stages: recovery, recrystallization and grain growth. Recovery usually occurs at low temperatures and involves thermally activated motion, condensation, and annihilation of point defects and specifically annihilation and rearrangement of dislocations [5]. Here the recovery stage can be ignored due to the very short period of the recovery process at 1350 °C. In this study, only the process of recrystallization will be investigated.

Fig. 1 shows light optical micrographs of W50, W67 and W90 annealed at 1350 °C for selected times, which are the status of as-received, partially recrystallized and fully recrystallized microstructures. Obviously, with the increased deformation ratio, the shape of the crystal grains is more elongated and the grain

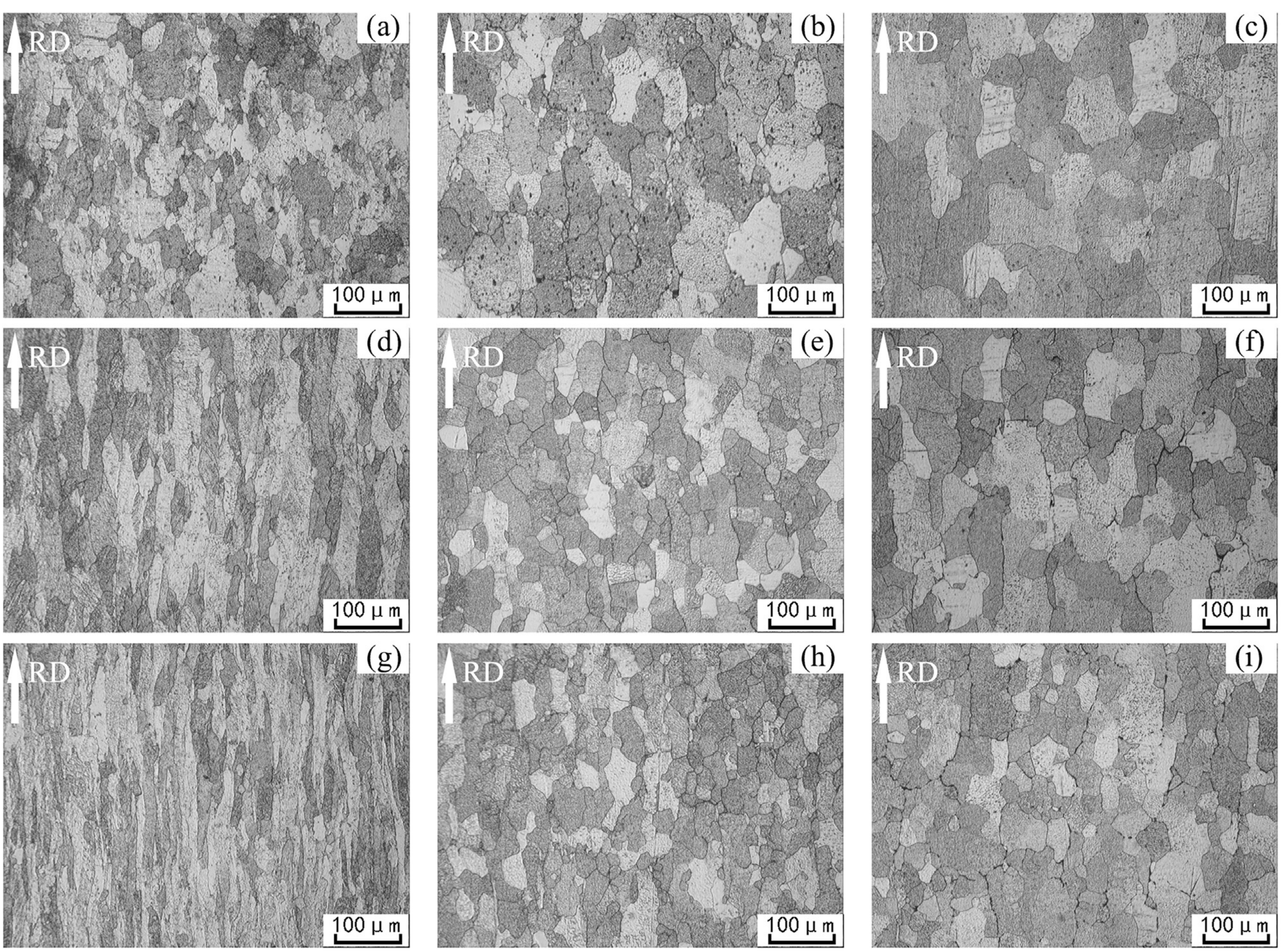

Fig. 1. Microstructural evolution of W50, W67 and W90 annealed at 1350 °C for various times: (a) 0 h, (b) 3 h and (c)23 h for W50; (d) 0 h, (e) 1.5 h and (f) 15 h for W67; (g) 0 h, (h) 1 h and (i) 11 h for W90.

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