Study of the dynamic recrystallization of Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloy in β-forging process via Finite Element Method modeling and microstructure characterization

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\begin{abstract}
By integrating the thermomechanically coupled simulation with the mathematically modeling of microstructure evolution using Finite Element Method (FEM), the study of the dynamic recrystallization (DRX) of Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloy in β-forging process is conducted. Through physical experiment, microstructure characterization and FEM-based microstructure modeling, the DRX behavior of the Ti-alloy in β-forging process is extensively explored. The effects of plastic deformation strain, strain rate and deformation temperature on the DRX of the Ti-alloy in terms of DRX volume fraction, DRX grain size and the average grain size are systematically investigated. The simulation results show that the increase of plastic deformation strain, deformation temperature, and strain rate contributes to the DRX of the alloy. The simulation and experimental results further reveal that the FEM-based microstructure evolution modeling is able to predict the DRX behavior and the microstructure evolution of Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloy in β-forging process.
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\section{Introduction}

Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloy is a desirable structural material for aeroengine and other aerospace components due to its good mechanical and high temperature properties [1–4]. This Ti-alloy is usually forged at the temperature of 30–50 °C below its (α+β)/β phase transformation temperature by the traditional hot forging process. The traditional forging process generates equiaxed microstructure, consisting of equiaxed alpha grains in the transformed β matrices. In general, the equiaxed microstructure possesses high ductility and thermal stability. However, the high-temperature mechanical properties, fatigue properties, and the resistance to crack growth and propagation of Ti-alloys forged by this process, are not satisfactory. To overcome these disadvantages, β-forging process for Ti-alloys was developed. Compared with the conventional forging process, the parts fabricated by β-forging process have lamellar microstructures in the transformed β matrices, consisting of lamellar alpha grains and thus have advanced properties including good high-temperature creep property, impact and fracture toughness [5,6]. To achieve the desired mechanical properties of the forged products, understanding of the microstructural evolution of workpiece in forging process is needed. Therefore, how to find a way to predict and analyze the microstructure evolution and deformation behavior of Ti-alloys in β-forging process under different forging conditions, including different strains, strain rates, and deformation temperatures, is a nontrivial issue.

The effects of strain rate, deformation temperature and true strain on forged product defects and forging process optimization have been studied by using numerical simulation method in the past two decades [7–11]. But only few researches on microstructure evolution by using this method have been conducted. In β-forging of Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloy, the alloy undergoes a series of microstructure evolution processes such as dynamic/static recovery, recrystallization and grain growth, which have a great effect on final product quality. DRX is of practical importance as it softens the alloy in the hot forming process and plays an important role in microstructural evolution. It also further affects the mechanical properties of the β-forged products. Therefore, it is of great importance to investigate the DRX behavior of the alloy in hot forging process, which is also the impetus to further investigate the underlying physics of this behavior.

DRX has been investigated by many researchers. As a pioneer of the numerical modeling of microstructure evolution, Sellars developed a set of mathematical models to analyze the microstructure evolution of carbon steel in hot rolling process two decades ago [12,13]. After that, a few investigators proposed an empirical equation to analyze the microstructure evolution of carbon steel [14–16]. By using the classical microstructural evolution models,