

Microstructure simulation of GH4066 turbine disc in forging process

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Abstract. GH4066 is a new type of wrought superalloy used to fabricate full-size high-pressure turbine disc for aero-engine with a diameter of more than 600 mm and a working temperature above 700 °C by advanced casting-forging technology. In this paper, the material models including the constitutive relation model, the peak strain and critical strain model, the dynamic recrystallization and grain size model are all obtained based on the flow stress measured by thermo-physical simulation test. And these microstructure evolution models are embedded into the finite element software Deform to simulate the hot forging process of GH4066 turbine disc. As a result, the microstructure changes in different regions on the turbine disc during the hot forging process were calculated, and the dynamic recrystallization and grain growth were analyzed. Thus, the microstructure evolution law of the turbine disc during hot forging process was obtained, which can provide a reference for the forging process optimization and microstructure control, and it is of great significance to the popularization and application of this new material.

1. Introduction

The main composition of the new wrought superalloy GH4066 is similar to that of René65 alloy in the United States and the volume fraction of the strengthening phase γ' is 43.0%. It can be used to fabricate the full-size high-pressure turbine disc for an aero-engine by advanced casting-forging technology, with the diameter more than 600 mm and working temperature above 700 °C, thus breaking through the bottleneck of producing high-pressure turbine discs with deformation technology [1-2]. In this research, the nominal composition of this material is C0.03%, Cr16.0%, Co 13.0%, Fe 1.0%, Ti3.7%, Al 2.1%, Nb 0.7%, Mo 4.0%, W 4.0% and Ni surplus. At present, the microstructure and properties controlling is the key technology for the high-pressure GH4066 turbine disc forging process.

2. Flow stress test and microstructure evolution models

Flow stress refers to the metal's ability to resist shape change and permanent deformation, which determines the metal's plastic deformation performance. And establishing a reasonable flow stress model for the material with specific composition has always been the focus of attention in the field of numerical simulation of hot forming process [3-5].



2.1. Flow stress test

The flow stress test was operated on Gleeble3800, the sample size and test course are shown in Figure. 1. In order to obtain homogenized original grain structure, the samples were heated to 1200°C at 20°C/s, and then cooled to 800°C, 900°C, 1000°C, 1100°C, 1150°C at 5°C/s, and the deformation rates was 0.0003S-1, 0.001S-1, 0.01S-1, 0.1S-1, 1S-1 and 10S-1 respectively. By the test, the stress and strain values under different deformation conditions of this material were obtained.

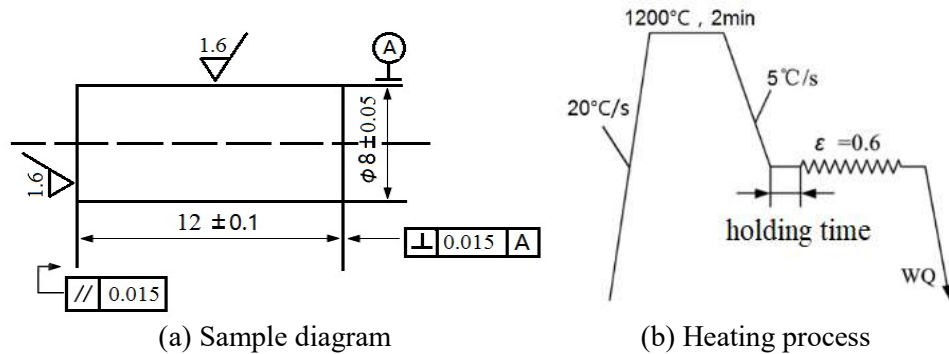


Figure.1 The high-temperature flow stress test

2.2. Microstructure models

Based on the test results and the Avrami equation, the microstructure models of this material were established, including:

Constitutive model:

$$\dot{\varepsilon} = 9.91 \times 10^{31} [\sinh(0.0056 \times \sigma)]^{4.1173} \exp(-105418.57 / T)$$

Peak strain model:

$$\varepsilon_p = 0.00078 \dot{\varepsilon}^{0.0661} \exp(57781.6548 / RT)$$

Critical strain model:

$$\varepsilon_c = 6.24 \times 10^{-4} \dot{\varepsilon}^{0.0661} \exp(57781.6548 / RT)$$

Dynamic recrystallization volume fraction model:

$$X_{drex} = 1 - \exp[-0.4514 \left(\frac{\varepsilon - 0.8\varepsilon_p}{\varepsilon_{0.5}} \right)^{1.14045}] \quad \varepsilon_{0.5} = 6.129 \times 10^{-3} \dot{\varepsilon}^{0.1008} \exp(41204.73 / RT)$$

Grain growth model:

$$d_{rex} = 328.099 \varepsilon^{0.193} \dot{\varepsilon}^{-0.0897} \exp(-27041.28 / RT)$$

3. Numerical simulation of forging process for GH4066 turbine disc

3.1. Plastic properties of Superalloys

Recrystallization has a great influence on the microstructure and service performance of the wrought superalloy during hot processing. The grain of turbine disc mainly controlled by the forging process not the heat treatment. By grain refinement, the yield and fatigue strength, the plasticity and impact toughness of the metal can be improved. By the microstructure evolution simulation, the dynamic recrystallization and grain growth during deformation can be analyzed [6-11], which can provide basic datas for the microstructure control and optimization of the turbine disc during forging process.

3.2. Numerical modeling of forging process for GH4066 turbine disc

A turbine disc mainly consists of four parts: the wheel core, hub, spoke plate and the flange. It serves in a aeroengine with high temperature, serious corrosion and complex stress. Therefore, its mechanical properties and microstructure uniformity are required to be very high. As the basic requirement, the mechanical properties must be improved to obtain the uniform internal microstructure in the processing

technology. Before the numerical simulation, the geometric models of the turbine disc and forging dies should be established and assembled, as shown in Figure.2.

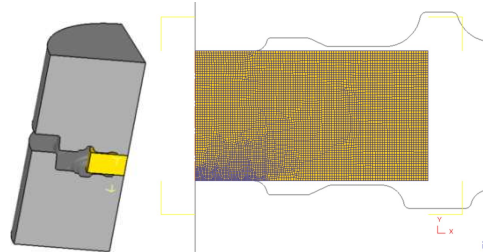


Figure.2 The 3D numerical simulation model and mesh

Based on the above model, the microstructure models of the material including the constitutive relation, peak strain, critical strain, dynamic recrystallization and grain growth models are all embedded into the finite element analysis software Deform to simulate the forming process of the turbine disc.

4. Simulation results and microstructure evolution analysis

4.1. The dynamic recrystallization and average grain size calculation during the deformation process

Figure. 3 shows the mean grain size distribution on the turbine disc with different deformation. Obviously, the average grain size decreases gradually with the increase of deformation. Before deformation, the initial grain size is 44.9 micron, but it is 35.85 micron after the deformation and the minimum grain is 25.8 micron. Therefore, the grain size is refined in the forging process.

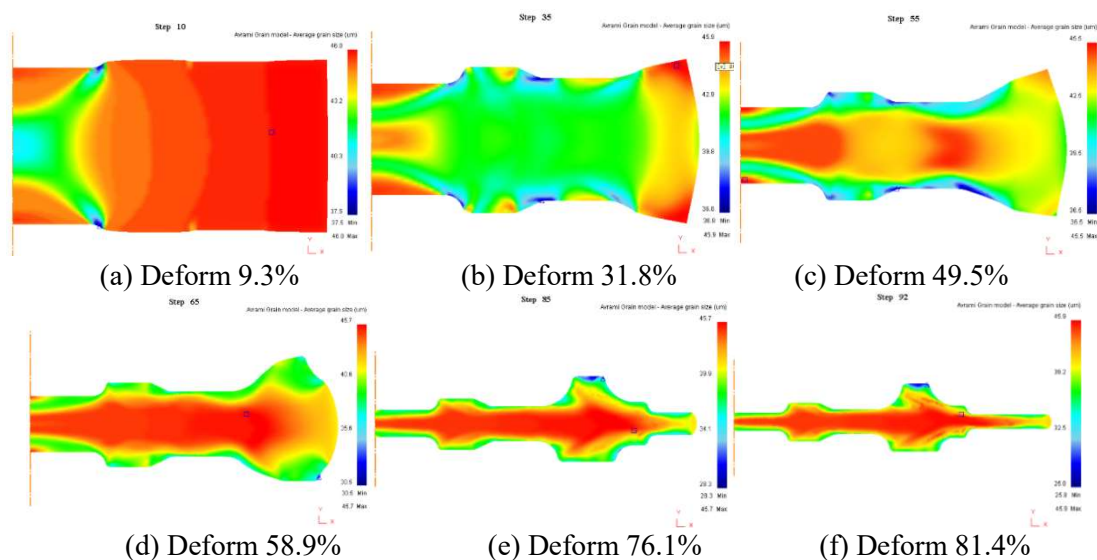


Figure.3 The grain size distribution on the turbine disc with different deformation

The deformation on different part of the turbine disc is different, so as the grain size. Figure.3 shows the grain size on different parts of the turbine disc in the deformation process. P1 is located in the core of the wheel, the grain size decreases first, then increases gradually to a certain value and remains unchanged at last. It indicates that recrystallization occurs earlier in this region, and then the grain grows up gradually to a stable value with the increase of deformation. P3 and P7 are located at the spoke plate and P6 is located at the hub center. The grain size of those points change similarly to that of P1, but the recrystallization occurs later than that of P1 and reaches to the dynamic equilibrium. P4 and P5 are located on the contact surface between the hub and the dies, and dynamic recrystallization occurs at the

latest. P2 is located in the middle part of the hub, the recrystallization occurs earlier as the grain grows with strain increasing, and the final grain size is small than that on P6, P3, P7 and P1. P8 is located at the flange of the wheel, and the final grain size is higher than P4.

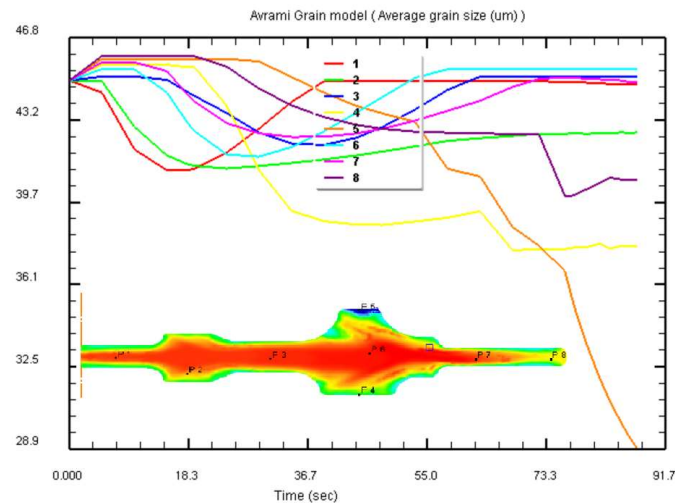


Figure.4 The grain size on different parts of the turbine disc in forging process

As the calculation results, the dynamic recrystallization volume fraction on the turbine disc during deformation is shown in Figure.4. Obviously, the dynamic recrystallization occurs with the deformation increasing from 9.3% to 81.4%. The earliest dynamic recrystallization occurs in the core region, and from the core to the flange part, the dynamic recrystallization volume fraction increases gradually. At last, the dynamic recrystallization is completed on the whole parts when the deformation reaches to the maximum value(81.4%) except the contact area between the disc and dies.

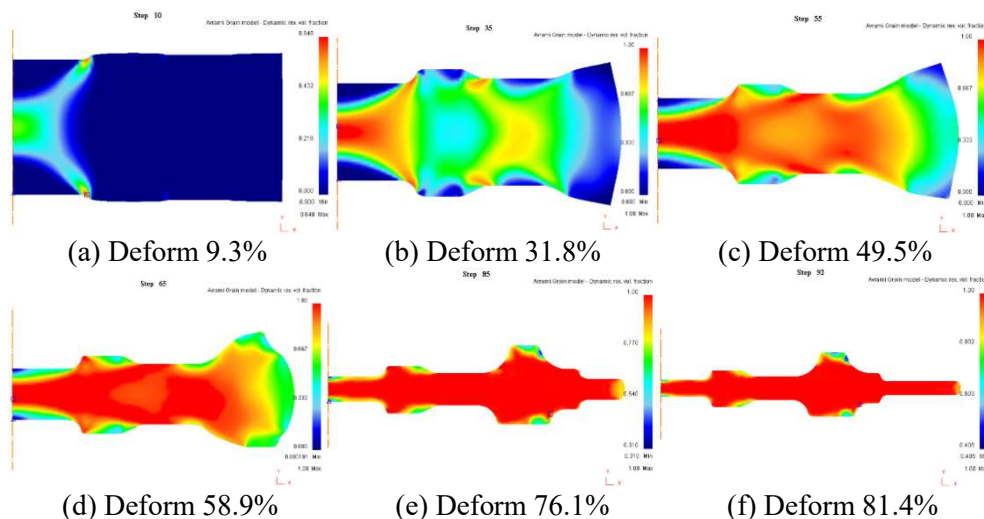


Figure.5 Dynamic recrystallization volume fraction on the turbine disc during deformation

Figure. 5 shows the dynamic recrystallization volume fraction on different regions of the turbine disc (P1~P8 in Figure.3) in forging process. It can be seen that the dynamic recrystallization on all regions are completed except P4 (89.1%) and P5(55.7%) which located on the contact region between the turbine disc and dies with high friction force. As to increase the dynamic recrystallization volume fraction and refine the grain size of this region, measures should be taken to reduce the friction.

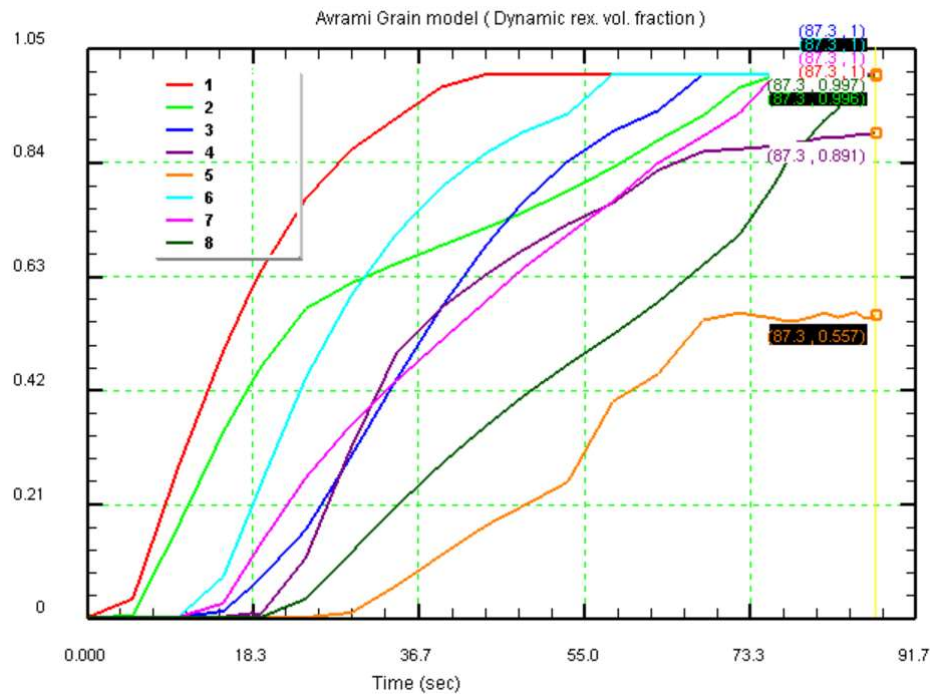
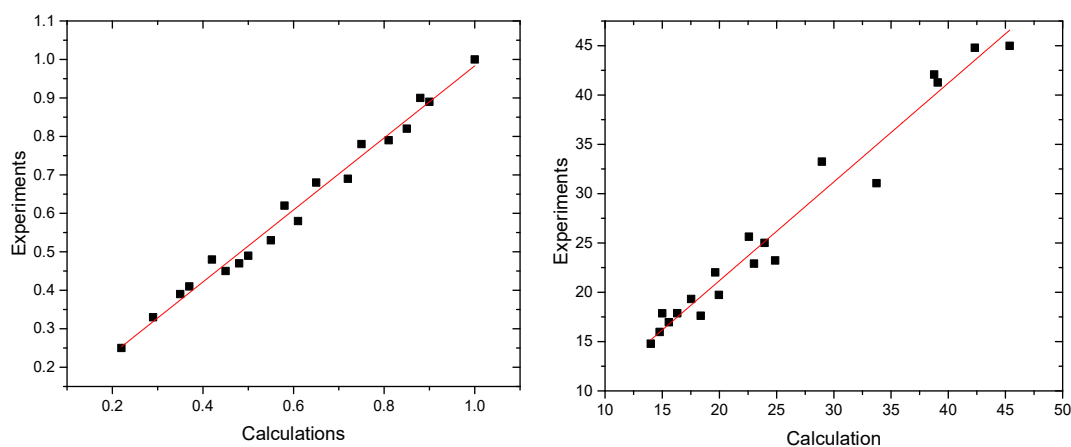


Figure. 6 The dynamic recrystallization volume fraction on different regions of the turbine disc (P1~P8 in Figure.3) in forging process.

4.2. Validation of the dynamic recrystallization and grain size model

From the above analysis, the influence of deformation, strain rate and temperature on the recrystallization can be explained by the recrystallization volume fraction and the grain size. In order to illustrate the calculation accuracy, the simulation results are compared with the experimental data as shown in Figure.6. The simulated values of the dynamic recrystallization volume fraction and the average grain size are compared with the experimental values when the deformation is 50%. As a result, the fitting slopes of the experimental points are 0.96 and 1.07 respectively, all the points are distributed near the regression line. Therefore, the experimental values are very close to the simulated values, and the model reliability is numerically verified.



(a) The dynamic recrystallization volume fraction (b) the average grain size

Figure.7 Comparison between the simulation and experimental results with 50% deformation

5. Conclusion

In this paper, the high temperature flow stress of GH4066 superalloy was tested and the microstructure evolution models were all established. These models were embedded into the finite element code and the hot forging process of the GH4066 turbine disc was simulated. As a result, the microstructure evolution rules on the different regions of the turbine disc during deformation were obtained. It shows that this method can be used to analyze the forging process and control the microstructure in the deformation process of the GH4066 turbine disc.

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