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EFFECTS OF PROCESS PARAMETERS ON GRAIN SIZE DURING ISOTHERMAL FORGING OF A TC6 ALLOY

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Abstract

Grain size of the α phase is computed during isothermal forging of the TC6 aerofoil blade, by combining FE with the Yada's model of grain size. The present results illustrate the grain size and distribution of the α phase during isothermal forging of the TC6 aerofoil blade in detail. The computed results show that height reduction, deformation temperature, hammer velocity and friction have significant effect on distribution of the equivalent strain, and that height reduction, deformation temperature and hammer velocity have more significant effect on grain size of the α phase than friction between billet and die.

Keywords: titanium alloy, aerofoil blade, gain size, numerical simulation

1 Introduction

It is well known that microstructural change is undertaken in metal forming, for example, static and dynamic recovery, dynamic recrystallization and grain growth. It is more important that those changes have great significant on deformation performance and properties of work-piece. Therefore, many researchers pursue to predict the final microstructure, the properties and the deformed defect of work-piece, by combining FE with a model for microstructural evolution [1,2] and to optimise the deformation process and tools design by simulating microstructural evolution [3].

Kang investigated perform design of precision forging blade by FEM [4]. Na simulated the evolution of grain structure in the process of two-step blade forging using the 3D FE simulator combined with a microstructural model [5].

The objective of this work is to explore a combination of FE with microstructure evolution and to simulate grain size of the α phase during isothermal forging of the TC6 aerofoil blade. Meanwhile, effects of process parameters on deformation distribution and changes in grain size during the forging process are investigated.

2 Fundamentals of FE simulation

The chemical composition of a TC6 alloy is 6.29Al, 1.42Cr, 0.42Fe, 2.71Mo, 0.33Si and Ti. The isothermal compression experiments with constant strain rate were conducted in a

THERMECMASTOR–Z simulator. The measurement of microstructure was carried out using a Leica LABOR-LUX12MFS/ST microscope [6].

2.1 Constitutive relationship

Analyzing the experimental data, Arrhenius' equation was employed to express the deformation performance during isothermal forging of the TC6 alloy. The relative error between the calculated results of equation (1) and the experimental is not more than 10%.

$$\dot{\varepsilon}\exp(\frac{Q}{RT}) = A\sinh(\alpha\sigma)^n \tag{1}$$

where, $\dot{\varepsilon}$ is equivalent plastic strain rate; σ is flow stress (MPa); R is gas constant (8.314J/mol·K^{-1}); T is absolute temperature (K); Q is activation energy of diffusion (kJ/mol). Constants A, n, α and Q are estimated in Ref. [7].

2.2 Grain growth model

In Yada's equation [8] for microstructural evolution, grain growth is related to the threshold strain. Yada pointed out that grains would grow as the true strain overtakes threshold, i.e., if $\bar{\varepsilon} < \varepsilon_c$, then $d = d_0$, if $\bar{\varepsilon} \geq \varepsilon_c$, then $d = c_1\dot{\bar{\varepsilon}}^{-c_2}e^{-c_3\frac{Q}{RT}}$. In which $\bar{\varepsilon}$ is equivalent plastic strain, ε_c is threshold of equivalent plastic strain ($=c_4e^{\frac{c_5}{T}}$); d and d_0 are concurrent and initial grain size (μm). According to the experimental results, constants c_1, c_2, c_3, c_4 and c_5 are 10844, 0.0276, 0.224, 0.0126, 1605.9, respectively.

2.3 Friction model

Simulating the isothermal forging of a TC6 alloy, friction force between billet and dies presented in the following equation (2).

$$f = -mk\left\{\frac{2}{\pi}tg^{-1}(v_n / v_0)\right\} \tag{2}$$

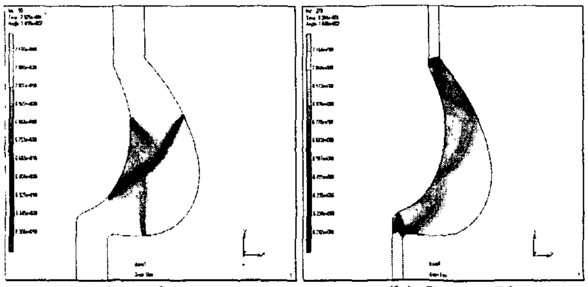
where, k is the materials' shear strength (MPa), v_n is the relative slip velocity between billet and dies, v_0 is a smaller positive constant ($10^{-3} \sim 10^{-4}$).

3 Simulation results and discussion

The MSC/Dytran software is used to simulate the isothermal forging of a TC6 aerofoil blade. The initial dimension of billet is 50mm in diameter. When simulating the forging process of a TC6 aerofoil blade, deformation temperature, hammer velocity and shear factor (m) of friction were 860~940°C, 9~3000mm/min and 0.1~0.3, respectively.

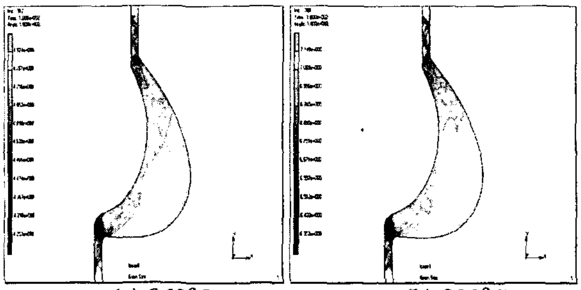
3.1 Effect of height reduction on grain size

In the early stage, there is the region with large strain and fine grains near to interface between upper die and billet, and there are those with coarse grains between lower die and billet. The region with the fine grains enlarges with an increase in height reduction. As the increasing of height reduction, grains are well distributed and the difference between the maximum and the minimum of grain size is to decrease. Fig.1 illustrates distribution of grains at different height reductions with 920°C of deformation temperature, 30mm/min of hammer velocity and 0.2 of friction factor (m).



(a) Step 90 (b) Step 270

Fig.1: Effect of height reductions on grain size



(a) 860°C (b) 920°C

Fig.2: Effect of temperature on grain size

3.2 Effect of deformation temperature on grain size

Dynamic recovery and recrystallisation is the predominant mechanism of microstructural evolution in isothermal forming of titanium alloy, in which the microstructural evolution is sensitive to deformation temperature. The computed results show that the grain size increases with an increase in deformation temperature. It is because the mobility and slide velocity of grain boundary increase with an increase in deformation temperature, resulting in high rate of grain growth. Fig.2 illustrates the effect of deformation temperature on grain size in the final stage with 30mm/min of hammer velocity and 0.2 of friction factor (m).

3.3 Effect of hammer velocity on grain size

Grain size decreases with an increase in hammer velocity. Meanwhile, the region with fine grains enlarges with an increase in hammer velocity. The difference of the maximum grain size at different hammer velocities is smaller than that of the minimum grain size, as shown in Table 1. It is because the recrystallisation time is different at different hammer velocities.

Tab. 1: Comparison of grain size at different strain rates

Hammer velocity (mm/min)	30	300	3000
d_{max} (μm)	7.15	11.89	12.06
d_{min} (μm)	6.35	5.17	5.66

3.4 Effect of friction on grain size

The region with large grains decreases with an increase in shear factor (m) of friction. In general, effect of friction on grain size is slight.

4 Conclusions

Deformation region with large strain appears near to interface between upper die and billet in the early stage, and then moves toward the center of billet, and reaches at the flash in the final stage. The difference between the maximum and the minimum of equivalent strain increases with an increase in height reduction. The maximum equivalent strain exhibited near to interface between upper die and billet results from the strong friction.

Height reduction, deformation temperature and hammer velocity has significant effect on grain size, and friction between die and billet does slight. The larger the height reduction is, the more well distributed the grain is. And the higher the deformation temperature is, the larger the grain size is. The low hammer velocity result the grain size in billet to be well distributed, but the grain size decreases with an increase in hammer velocity. In the final stage, the finest grain appears near to interfaces between dies and billet.

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