Research Status of Influencing Factors on Superplastic Properties of Titanium Alloy

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Abstract. Titanium alloy is an important structural material with high specific strength, excellent corrosion resistance and high heat resistance. It has been widely used in aviation, automotive industry and other industries. But its cutting performance is poor, especially the manufacture of some complex parts, the rate of finished products is very low. Superplastic processing is very effective to improve the rate of finished product. In view of this, the effects of grain size and deformation temperature on the superplastic properties of titanium alloy were investigated. The superplastic deformation behavior of the titanium alloy under different influencing factors was also reviewed.

Keywords: Titanium Alloy, Superplasticity, Grain Size, Strain Rate, Deformation Temperature.

1 Introduction

Superplasticity includes large deformation, small deformation resistance and necking resistance [1].

Titanium alloy has been widely used in the aerospace field due to its good comprehensive properties, such as small density, high specific strength and excellent corrosion resistance. It accounts for about 70% of the total titanium output [2-3]. However, the deformation mechanism of titanium alloy is complex, and deformation resistance is very large in the forming process. Especially for some complex the special-shaped structures, conventional forging is difficult[4].Therefore, superplastic forming technology can be used to overcome some difficulties and shortcomings in conventional forging, such as the complex shape forming, the large web structure with thin web and high reinforcement. Because the forming efficiency of conventional superplastic technology is low, which greatly limits the practical application of Superplasticity of titanium alloys, in order to expand its application, the current low temperature superplasticity of titanium alloy and high strain rate superplasticity has become an important research direction [5-7].

Superplasticity is the comprehensive mechanical performance of metal materials under certain conditions of the performance, many factors affect the superplastic behavior, including the grain size, deformation temperature, the strain rate, microstructure, deformation hardening, softening deformation, stress distribution, grain shape and etc. These factors directly or indirectly affect the ability of superplastic deformation and the change of strain rate sensitivity index m[1].Therefore, after fully mastering the factors that affect the Superplasticity of titanium alloy, the desired performance can be achieved in superplastic forming by controlling the experimental parameters. In view of this, this
paper summarizes the factors affecting superplastic behavior of titanium alloy, such as grain size, the train rate and deformation temperature.

2 Effect Of Grain Size On Superplasticity

The constitutive relation describe the superplastic deformation behavior of the general material [8].

$$\varepsilon = A \frac{D G b}{k T} \left( \frac{b}{d} \right)^p \left( \frac{\sigma}{\epsilon} \right)^n$$  \hspace{1cm} (1)

In the formula: The A is the material constant; the D is diffusion coefficient; the G is shear modulus; the E is elastic modulus; the T is deformation temperature; the ε is strain rate; the σ is flow stress; the b is Burgers vector; the k is Boltzmann constant; the d is grain size; the p is grain size index; then is stress exponent.

According to the above formula, grain size plays an important role in the superplasticity of materials. It can reduce the deformation temperature of the superplastic forming or increase the optimum strain rate by reducing the grain size.

He Hongbo studied that TC4 titanium alloy with different grain sizes (2,8,18µm) in temperature 860~950 degrees Celsius and superplastic tensile deformation behavior and microstructure evolution under strain rate 5x10^{-4}~5x10^{-9}S^{-1}. He also analyzed the influence of grain size on deformation behavior of the alloy superplasticity and deformation mechanism. Figure 1 shows that with the increase of grain size, the elongation decreases obviously. when the total area of grain boundary increase, the number of slip system increases, grain slippage and rotation are more coordinated, and the grain boundary is easy to slip. Therefore, the smaller the grain size, the greater the elongation of the alloy.

As to the effect of grain size on superplastic behavior of titanium alloy, it is found that the smaller the grain size, the larger the sliding grain boundary, which provides a large number of grain boundaries for grain boundary sliding, and the associated stress concentration increases, it is mainly concentrated in the grain boundary and its vicinity, which leads to the intragranular dislocation slip also concentrated in the vicinity of the grain boundary, playing a role in coordinating the grain boundary slip. At the same time, the grain size become smaller, when the equiaxed is better, the cavity size and density are smaller, and the easier the rotation and slip of grain. Therefore, in the superplastic deformation process of fine grained materials, grain motion and grain boundary arc are caused by grain boundary sliding and grain rotation, the grains are gradually arranged in the direction of the tensile axis, the material elongation rate has been greatly improved [10-11]. Therefore, an important way to improve the superplastic properties of titanium alloy is to refine the grain. At present, many refined grain technologies are used, such as large plastic deformation, thermomechanical treatment, mechanical alloying, hot hydrogen treatment etc..
3 Relationship Between Strain Rate and Superplasticity

Superplasticity is sensitive to strain rate. The superplasticity can be exhibited superplasticity only in a certain strain rate. Stress-strain curve and strain rate of superplasticity have a great relationship. As shown in figure 2[12], When TA15 is Superplastic stretched at 900°C, Stress-strain curves under different strain rates are shown. It can be seen from figure 2, with the decrease of strain rate, flow stress decreases gradually. In addition, when the strain rate decrease, the strain increases gradually which corresponding to the peak stress, which shows that the elongation is gradually increasing. The stress strain curves in Fig. 2 are also shown that with the decrease of strain rate, the strain hardening occurs, and the superplastic properties are improved, On the contrary, the elongation decreases. This phenomenon in the superplastic deformation process of other alloys also exist[13].

Fig.2 Effect of strain rate on stress-strain the curve (t=900°C)

The Fig. 3 is the influence curve of different strain rates on the elongation at the experiment[12]. As shown in Figure 3, with the decrease of strain rate, the elongation increases gradually. When the min strain rate is 3.3x10-4s-1, the max elongation is 1074%, and at the higher
strain rate, TA15 alloy also has good superplastic properties. When the strain rate is 1.1x10^-2s^-1, an elongation of 558% is obtained, which mainly due to the fact that the original microstructure of the sample is very uniform and mainly composed of small equiaxed grains. Therefore, the strain rate can be greatly improved when the alloy obtains better superplasticity. The related reports also show that the deformation rate can be greatly improved when superplastic deformation of fine grained materials[14-16].

![Fig.3 The Relationship between strain rate and elongation](image)

On the other hand, Zhao Zhang[17], et al investigated the influences of strain the rate on strain rate sensitivity index m and microstructure of TC21 titanium alloy during superplastic tensile. It is found that the titanium alloy is stretched at the best initial strain rate(3.3×10^-4s^-1), the tensile deformation zone of the alloy is obviously aggregated and recrystallized due to the long time high temperature and large deformation, and a considerable amount of grains merge into irregular flakes. When the strain rate is 5.5x10^-5s^-1, The microstructure of the sample chuck and the Middle Deformation Zone is further coarsened and the superplastic property is reduced. This shows that the low strain rate is not necessarily the best condition for superplastic forming of titanium alloy, and the strain rate should not be too low.

4 Effect of Deformation Temperature on Superplasticity of Titanium Alloy

Superplastic deformation is the behavior of materials at a certain temperature range. The deformation temperature affects the superplastic forming properties of titanium alloy. The reduction of superplastic temperature is beneficial to improve the efficiency of superplastic forming, save energy and reduce the loss of die. Therefore, It is very important to study the effect of deformation temperature on superplasticity of titanium alloy.

Li Xin[18] takes TC11 titanium alloy with equiaxed crystal structure as the object of study, The effect of deformation temperature on tensile superplasticity was studied at high the strain rate of 0.001 S^-1 at different deformation temperatures. Figure 4 is the physical diagram and elongation of TC11titanium alloy sample before and after drawing at different temperatures. It can be seen from Figure 4 that the TC11 titanium alloy exhibits superplasticity in the range of 810~980 °C in the α+β region, However, in the β region the superplasticity does not appear at the 1050 °C. For TC11 titanium alloy, superplasticity is difficult to occur in the beta phase region by constant strain rate tensile. The elongation increased with the increase of temperature ,it reached the maximum value at 595%,As the temperature continues to rise, the elongation begins to decrease, the elongation has decreased to 159% at 980 °C. The reason may be that when the temperature is less than 900 °C, the kinetic energy of the atom increases with the increase of temperature, so the dislocation activity increases, the diffusion creep and intergranular the slip effect increase, which leads to the increase of plasticity. When the temperature is above 900°C, the content of α phase begins to decrease obviously, which can not effectively prevent the growth of β grain, leading to the decrease of plasticity. It is shown that the
optimum temperature of superplasticity is near 900°C, and maximum elongation is 595%. During the deformation process, there are intragranular deformation, dynamic recrystallization (or diffusion creep) and interface sliding, and the interface sliding appears at the interface of the α/β phase.

![Fig.4 physical figure and elongation before and after stretching](image)

5 Conclusion

Because the titanium alloy has excellent plasticity and extremely low flow stress in superplastic state, it is very beneficial to its forming, therefore, it is very important to study the influence factors of grain size, strain rate and deformation temperature. Studies have shown that the smaller the grain size is, the larger the sliding grain boundary is, and the coordination of grain boundary sliding is enhanced. At the same time, the smaller the grain size, the better the equiaxed property, the easier the rotation and sliding of the grain, and the greater the elongation of the material. Under certain conditions, the reduction of strain rate is beneficial to improve the Superplasticity of titanium alloy, but under low strain rate, the microstructure of titanium alloy will be further seriously coarsening, thus reducing the superplastic properties of titanium alloy. The superplastic deformation temperature of the alloy needs to be about half of its melting temperature. The high deformation temperature will reduce the content of the α phase, and can not effectively prevent the growth of the β grain, leading to the beginning of plastic reduction. Therefore, further study on the factors influencing superplasticity of titanium alloy can provide the theoretical basis for superplastic forming of titanium alloy.

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