Research on Superplasticity of 5A90-O Aluminum Alloy Sheet

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Abstract. The influence of temperature and strain rate on the 5A90-O had been researched by costant strain-rate tensile method. The result shows that, although 5A90-O is not an ideal superplastic material, under certain conditions, with a large extension rate, the maximum elongation is193.6%. The strain rate has a significant impact on the flow stress and tensile strength under T=375℃~500℃. With the decrease of strain rate, the load is reduced. Another important factor that affects the flow stress of 5A90 is temperature. Under the same strain rate, the flow stress of 5A90 is lower with the temperature increase. We choose the Backofen law as the constitutive equation of 5A90, the best condition of 5A90 superplastic deformation is T=400℃, $\varepsilon = 0.005s^{-1}$.

1. Introduction

Before 2020, the Tiangong-2 space station will be established preliminarily by China. From 2016, the spacecraft will be launched frequently. In order to improve the load capacity, the structural material which has light weight and high-strength had been researched. In this paper, our research target is 5A90-O Aluminum alloy, which is in Al-Li series. It has the advantage of low density, highly rigidity and excellent heat resistance. But use the traditional technology (cold stamping) to process a 5A90 thin shell will produce the following phenomena: low-plasticity and high-resilience, complex part is hard to form， at the same time, the costs of cold-stamping-mold will increase[1]. In aerospace field, if you want to form aluminum alloy thin-wall parts, the superplastic forming has been used normally. Because, when use superplastic forming process to aluminum alloy sheet, aluminum alloy has better plasticity, complex shape can be formed at one time, and under the high temperature, Aluminum alloy has almost no rebound spring-back, at the same time, it has simple mold structure. So, in this research, we used the high temperature one-way tensile test to find the best super-plastic parameters for 5A90, including temperature, strain rate and constitutive equation [2-3].

2. Experimental condition

Normally, if we want to find the parameters of superplastic material or superplastic materials with non ideal conditions, we need to do the same strain rate high temperature one-way tensile tests to get it. Then treat experiment data, we can get the elongation of 5A90, stress strain curve, and the Backofen constitutive equation, which include strain-rate sensitivity exponent m and the corresponding constant K [4].

In this paper, the material was provided by South Aluminum, 5A90 aluminum alloy chemical composition is shown in Table.1, and the original thickness of sheet is 1.4 mm.

Table.1 Chemical composition of 5A90 alloy in wt%

Mg	Li	Zr	Cu	Fe	Si	Al
5.29	2.12	0.12	0.03	<0.2	<0.15	Bal.

The dimension of tensile specimen was shown in fig.1.Tensile test is carried out in TG2000-20 universal testing machine. Besides it use retrofitted temperature control unit and the load-displacement sensor to achieve the same strain rate deformation. Finally, we can get the load-displacement curve.

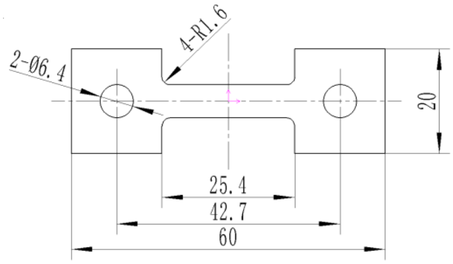


Fig.1 The dimension of tensile specimen

Through consulting sources, we had selected six temperature points:375,400,425,450,475,500℃, and five strain rate points: ε=0.00025s^{-1}, ε=0.0005s^{-1}, $\varepsilon = 0.001s^{-1}$, $\varepsilon = 0.005s^{-1}$, $\varepsilon = 0.01s^{-1}$.

3. Experimental results analysis and discussion

3.1. The elongation of 5A90 aluminum alloy

One-way tensile tests were carried out at different temperatures and strain rates as is stated above. The result of elongation had shown in fig.2. When the temperature is 375℃, the elongation of 5A06 is low, when the temperature is low, grain boundary sliding is difficult to conduct, which caused the low elongation. When the temperature is 400℃, all of the elongation can exceed 100%. The largest elongation is 193.6%. When the temperature is over 450℃, the temperature is too high, grain growth quickly, softening is less than hardening, the material appeared to shrink neck earlier, then break quickly.

When the maximum extension rate occurs, T=400℃, $\varepsilon = 0.01s^{-1}$, so this combination of temperature and strain rate is the best process parameters.

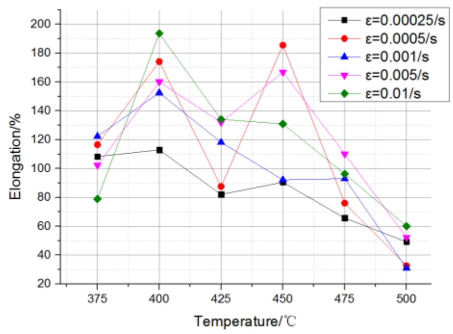
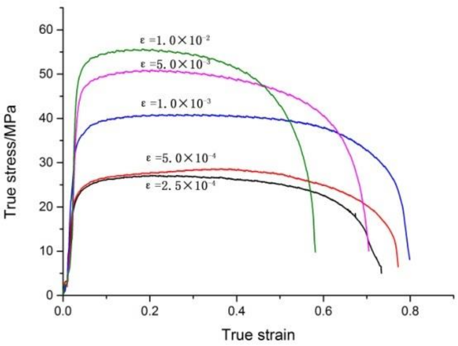


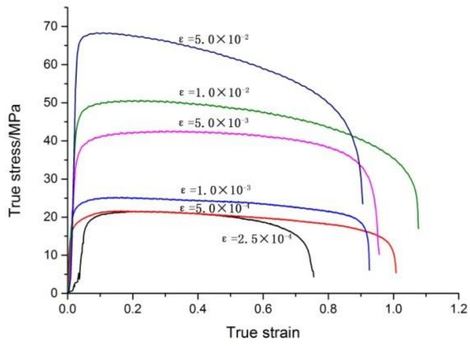
Fig.2 5A90 Al-Li alloy superplasitc one-way tensile elongation under different deformation condition

3.2. Mechanical property

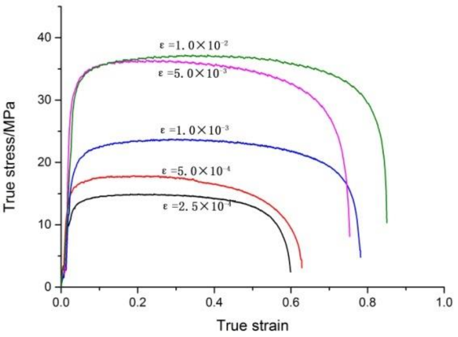
In fig.3, 5A90 alloy flow curves under different strain rate at the same temperature had been shown. It can be seen that the load reaches its maximum value quickly, and then it slows down, finally 5A90 breaks. The load gradually reduces with the decrease of strain rate.



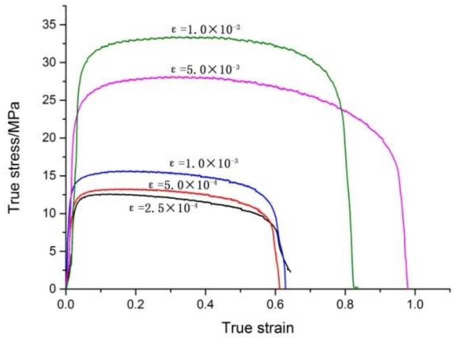
（a）375℃



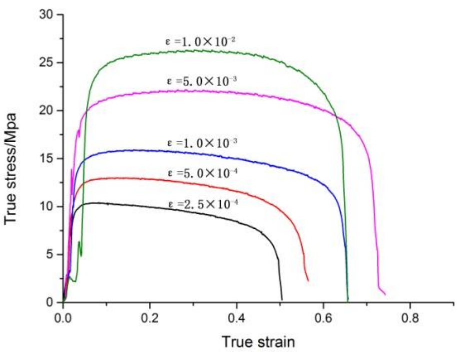
(b) 400℃



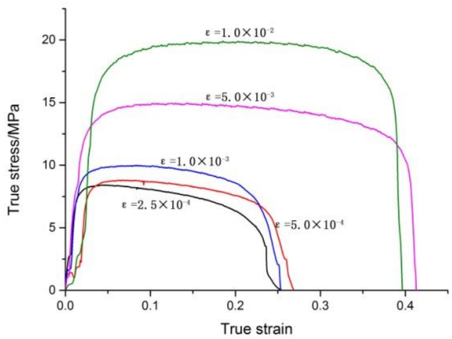
(c) 425℃



(d) 450℃



(e) 475℃



(f) 500℃

Fig.3 5A90 alloy flow curves under different strain rate at the same temperature

The relationship between dislocation velocity and shear stress about 5A90 had shown in equation (1). In this equation, V_0 is initial dislocation velocity; V is final dislocation velocity; A is the activation energy of material; τ is shear stress; T is the temperature of deformation. Through it, we can know that the flow stress is reduced inevitably when there shear stress is down. The movement velocity of dislocation decreased rapidly when the strain rate dipped to 0.0001/s. From the macro view, it is shown that the flow stress decreases rapidly. So the 5A90 Al-Li alloy is a kind of positive strain rate sensitive material.

$$v = v_0\, exp\left(\frac{A}{\tau T}\right) \tag{1}$$

On high temperature, the flow stress of 5A90 aluminum alloy increases rapidly and then tends to be stable when under different deformation conditions. But in this stage, the curves shows like serrate. The result of this phenomenon is that the dislocation density is increasing all the time when the material in the process of deformation. So the resistance of dislocation movement has increased which the load has augmented on the macro. It shows that the work hardening has appeared. At the same time, the dislocation and the energy density increased, when the accumulated energy is over the activation energy of recovery and re-crystallization, the dynamic recovery or dynamic re-crystallization will happen. It is a softening process. Because the hardening and softening coordinated all the time, in the end, the serration been emerged.

The temperature is another important parameter in superplastic forming, so the effects of temperature on the mechanical properties under high temperature needed to study.

Fig.4 shows the curves for 5A90 aluminum alloy, which were stretched at different temperature points when the strain rate$\dot{\varepsilon}$=0.00025s^{-1}, 0.0005s^{-1}, 0.001s^{-1}, 0.005s^{-1}, 0.01s^{-1}. We can know that under the same strain rate, the flow stress of 5A90 is lower when the temperature increased. The reason is when the temperature is high, the molecular motion is active, so the kinetic energy is improved, atomic vibration amplitude is larger, the activity of dislocation and vacancy is active, more and more slip system have been started. At the same time, dynamic recovery and re-crystallization has occurred, it can bring to a certain degree of softening. These factors work together to reduce critical shear stress, so the flow stress of 5A90 is reduced.

It follows that, under the high temperature, the deformation of 5A90 Al-Li alloy is a coordinate process which is hardening and softening. The work hardening is mainly derived from the deformation, the softening is mainly derived from the increased dislocation movement and dynamic recovery and re-crystallization. When the temperature is high, the mainly process is softening, on the contrary, is work hardening. On the macro, it shows that when the temperature increased, the flow stress reduced.

3.3. The constitutive eauation

In this paper, we had built the constitutive equation of the 5A90 aluminum alloy based on Backofen.

When plastic deformation occurs, the flow stress has mainly influenced by strain rate, strain, temperature and the size of grain, it has been shown in formula (2).But the temperature is invariant under superplastic deformation and since the material is 5A90, the relationship about follow stress σ, strain ε and strain rate $\dot{\varepsilon}$ can simplify as formula (3):

$$\sigma = f(\dot{\varepsilon}, \varepsilon, T, d) \tag{2}$$

$$\sigma = K\dot{\varepsilon}^m \varepsilon^n \tag{3}$$

In formula (3), K is a constant about material; m is strain rate sensitivity index; n is strain hardening exponent, but in superplastic, generally, the strain hardening does not appear, so its value is 0.

Finally, the formula about σ and $\dot{\varepsilon}$ can express as formula (4):

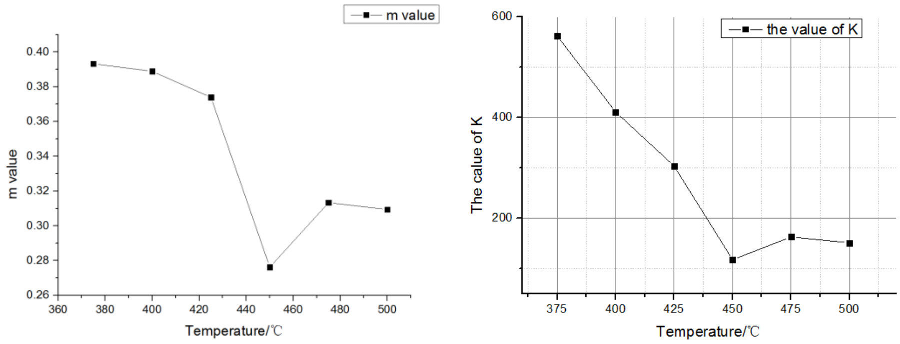
$$\sigma = K\dot{\varepsilon}^m \tag{4}$$

Generally, if you want to get the *m* about a material, you can through the same strain rate tensile method, constant velocity tensile method, velocity mutation tensile method and so on. In this experiment, the constant velocity tensile method is been picked.

Firstly, gain the stress strain curve of 5A90. Then select a stable section of the curve, converted it into $\ln\sigma^{-1}$—ε . The slope of the curve is *m*. The formula is (5).

$$m = \frac{d\ln\sigma^{-1}}{d\varepsilon} = -\frac{d\ln\sigma}{d\varepsilon} \tag{5}$$

After calculate, we can get the value of m, they have been shown in fig.4(a). With the temperature increased, the value of m reduced at first, and then increased slowly. Temperature has an important effect on m. In the condition of T=375℃, m=0.3932, material deformation is more uniform.



(a) (b)

Fig.4 The value of m and K
(a) Strain rate sensitivity index changing with temperature
(b) The value of K changing with temperature

When we get the value of m, we can through formula (4) to find the value of *K*, it has shown in fig.4 (b). With the temperature increased, the value of K reduced firstly, and then increased slowly. So T=400℃is the best temperature of deformation after take some factors in the practical production into account.

4. Conclusion

1. The best temperature of deformation for 5A90 Al-Li alloy is 400℃, under this temperature points, the maximum elongation is 193.6%.

2. The strain rate has a significant impact on the flow stress and tensile strength under T=375℃ ~500℃. With the decrease of strain rate, the load is reduced.

3. Another important factor that affects the flow stress of 5A90 is temperature. Under the same strain rate, the flow stress of 5A90 is lower with the temperature increase.

4. We choose the Backofen law as the constitutive equation of 5A90, the best condition of 5A90 surperplastic deformation is T=400℃, $\varepsilon = 0.005\text{s}^{-1}$.

5. References

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