Study of the hot deformation behavior in TA19

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Abstract: The high temperature deformation behavior and microstructure evolution of TA19 alloy in the temperature range of 920-1030℃, strain rate range of 0.01s-1-10s-1 and height direction reduction of 60% have been studied by hot compressing testing. The microstructure of TA19 alloy was observed and analyzed using Olympus/PMG3 optical microscope. The flow stresses were correlated with strain rate and the temperature by the constitutive equation. The results show that the flow stress of TA19 alloy increase quickly with the strain, then decrease with a steady value. The Q value obtained in the α+β region for TA19 was 586KJ/mol, and in the β region was 290KJ/mol. It was also found that in α+β region, dynamic re-crystallization easily occurred; in β region the dynamic re-crystallization is obvious at low strain rate and dynamic recovery is obvious at high strain rate.
Keywords: TA19 alloy; high temperature deformation; flow stress model; microstructure

1. INTRODUCTION

Most titanium alloys have been designed for aeronautical applications, where their excellent specific properties are fully employed. For example, TA19, IMI685 and Ti17[1-3] alloys are used for the manufacturing of air craft engine components, whose service temperature does not exceed 550 ℃.TA19 alloy as a kind of near α titanium alloy is used for the compressor disks and other airplane components, and is developed by the USA in the year 1974. Due to the addition of element Si, TA19 alloy has excellent thermo-strength and thermo -stability at the service temperature of 520 ℃. It is important to understand the relationship between deformation rate and temperature, since they are two important parameters that have significant effect on the development of microstructure and mechanical property. In this paper, the hot deformation behavior of TA19 alloy was investigated by the samples under the hot working condition of varying temperature and strain rate characterized by isothermal compression tests. Hence, the objective of the present paper is to study the flow behavior and to perform constitutive modeling of hot working process for TA19 alloy.

2. EXPERIMENT

The experimental material was supplied in form of forged bar with diameter of 47 mm. Its chemical composition in ωt. % is: 6.13Al, 2.14Sn, 3.93Zr, 2.18Mo, 0.1Si, 0.007N, 0.08O, 0.003H and Ti (balance). The nominal beta transus temperature for this alloy is 995℃ ±5℃. The initial microstructures of TA19 alloy is shown in Fig.1.

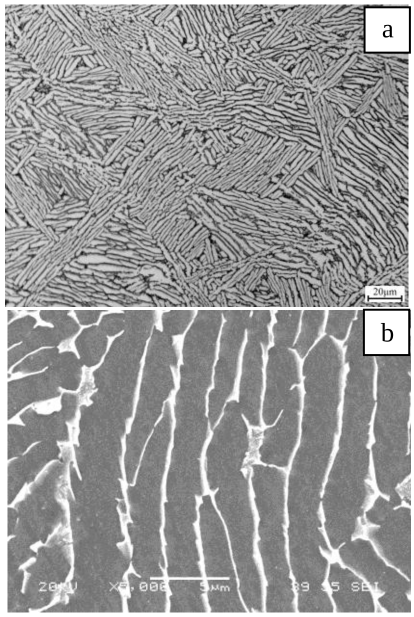

Fig.1 Initial microstructures of TA19 alloy (a) 0M; (b) SEM

Hot compressive deformation behavior of TA19 alloy at elevated temperatures was characterized by isothermal compression tests on Gleeble 1500. Cylindrical specimens of 8mm diameter and 12mm length were machined from the bar. The compressive tests were performed in deformation temperature ranging of 920-1030℃ and at strain rates from $0.01s^{-1}$ to $10\ s^{-1}$. The specimens were heated to the compression temperature at 5℃/s, held at least 300s and then deformed up to 60% height reduction under constant strain rate. The temperature was controlled by a thermocouple welded in the middle of the specimens. The deformation was controlled by the stroke and the strain was measured by means of a transverse strain gauge located at the middle of each specimen to eliminate any effects of the longitudinal gradient of temperature to and the friction at the anvils on the flow curves. After compression, the specimens were quenched immediately in water to preserve the hot deformed microstructures. The ends of the specimens were coated with graphite lubricant in order to reduce friction. Deformed specimens were sectioned parallel to the compression axis along the direction of centerline. The microstructure of TA19 alloy was observed and analyzed using Olympus/PMG3 optical microscope.

3. RESULTS AND DISCUSSION

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3.1 Flow behavior

Figure 2 depicts the flow curves of TA19 at different temperatures and strain rates. It can be observed that all of the flow curves exhibit an initial peak at the beginning of deformation process. It is because the rapid work hardening plays a leading role before the occurrence of soft action induced by dynamic recover and re-crystallization. Then, the flow stress decreases sharply to a near steady state, which all curves exhibit flow softening behavior, but the soft action induced by re-crystallization will be obviously stronger than that dynamic recover, and accordingly the flow stress will decrease rapidly after reaching the maximum instead of maintaining the steady-state as the soft action induced by re-crystallization.

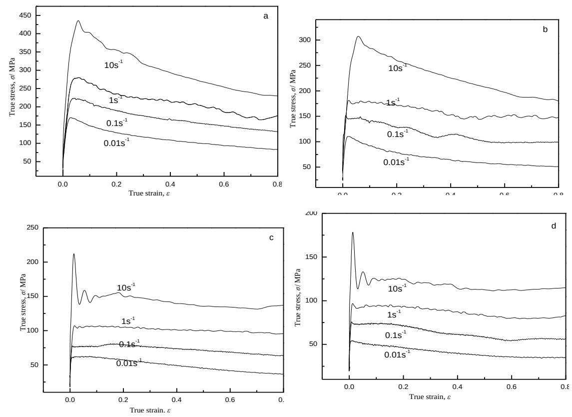

Fig.2 Flow stress curves of TA19 titanium alloy compressedat different deformation conditions

(a) 920℃; (b) 950℃; (c)1000℃; (d) 1030℃

Therefore, it can be concluded that the leading deformation mechanism in single phase β region is dynamic recover. So the flow stress is influenced obvious with deformation temperature and strain rate.

3.2. Constitutive relationship and activation energy

The dependence of the flow stress (σ) with the strain rate ($\dot{\varepsilon}$) and deformation temperature can be related using these three constitutive equations[4-6]:

$$\dot{\varepsilon} = A_1\sigma^n \exp(-Q/RT) \quad (1)$$

$$\dot{\varepsilon} = A_2 \exp(\beta\sigma)\exp(-Q/RT) \quad (2)$$

$$\dot{\varepsilon} = A_3[\sinh(\alpha\sigma)]^n \exp(-Q/RT) \quad (3)$$

Where A_1, A_2, A_3 are material constants, n is the stress exponent, Q is the apparent activation energy of deformation, R is the gas constant (8.3145 J mol^{-1} K^{-1}), and T is the deformation temperature.

Fig.3 shows the relationship between Inσ and ln $\dot{\varepsilon}$, and the plot shows a linear relationship, suggesting that the equation is valid. Fig.4 shows the relationship between Inσ and 1000/T.

From the Eq. (1), the Q value at a strain rate could be obtained as follows:

$$Q = R\left[\frac{d\left[\ln(\sigma)\right]}{d(1/T)}\right]_{\dot{\varepsilon}} \Big/ \left[\frac{d\ln(\sigma)}{d\ln\dot{\varepsilon}}\right]_T \qquad (4)$$

Where $\left[\frac{d\left[\ln(\sigma)\right]}{d(1/T)}\right]_{\dot{\varepsilon}}$ and $\left[\frac{d\ln(\sigma)}{d\ln\dot{\varepsilon}}\right]_T$ are the slopes of the curves from Fig.3 and Fig.4.

According to Eq. (4), the activation energy Q value can be calculated. In the case of TA19, the slopes in α+β and β regions were different and therefore the activation energy was separately calculated for the two regions.

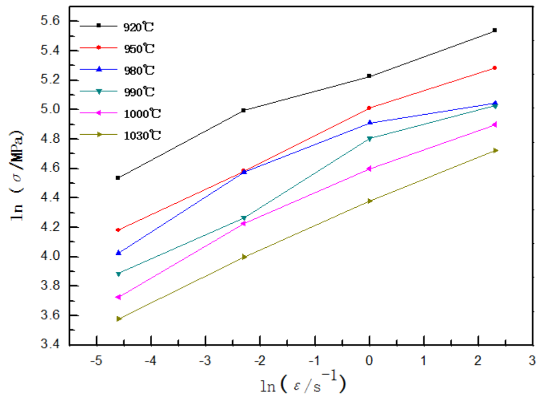

Fig.3 Variations of flow stress with strain rate

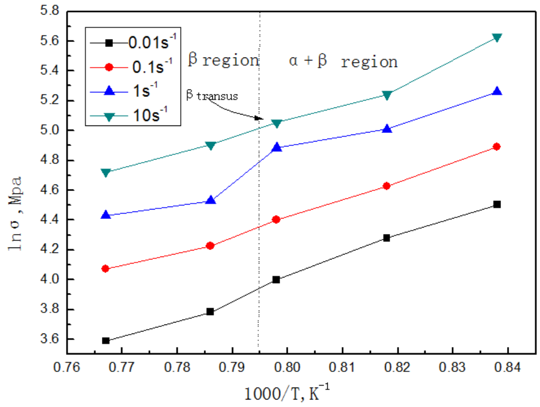

Fig.4 Variations of deformation temperature

The Q value obtained in the α+β region for TA19 was 586KJ/mol, comparable with that obtained by I.Philippart *et al* for IMI834 (703 kJ/mol)[7]. The calculated apparent energy in the β region was 290KJ/mol. It is well known that the deformation activation energy is an important physical parameter of deformation difficulty degree during hot deformation and activation energies for titanium alloys in the α+β phase region are usually much higher than that in single phase region. It indicates that the deformation mechanism is different between α+β region and β region and Q value decrease with increasing of deformation temperature. So it need be further studied according to the microstructure.

33. Microstructural observations

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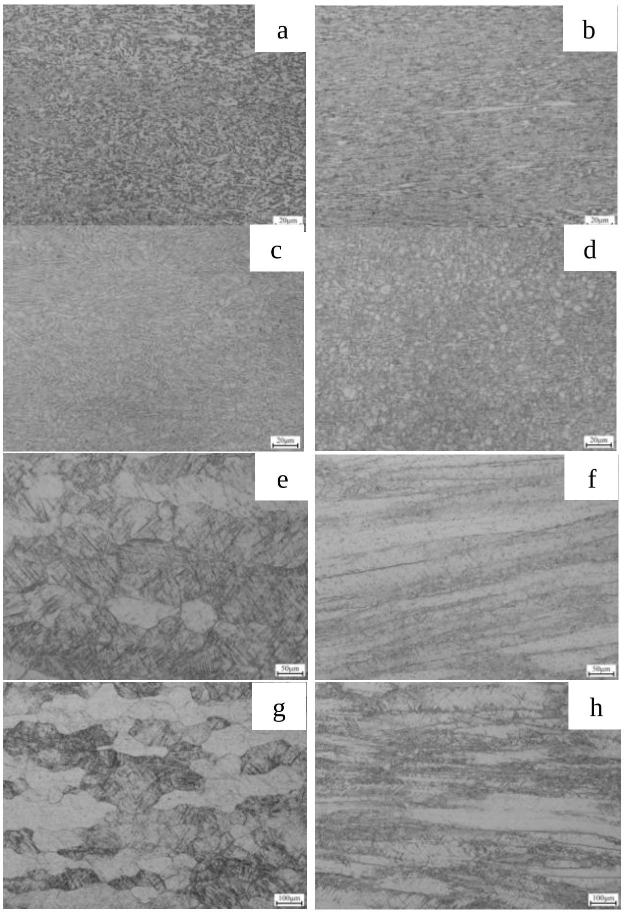

Fig.5 Microstructures of TA19 alloy deformed at: (a) 920℃ 0.01s^{-1}; (b) 920℃ 10s^{-1}; (c) 950℃ 0.01s^{-1}; (d) 950℃ 10s^{-1}; (e) 1000℃ 0.01s^{-1}; (f) 1000℃ 10s^{-1}; (g) 1030℃ 0.01s^{-1}; (f) 1030℃ 10 s^{-1}

Fig.5 shows the microstructures of the specimens at different deformation conditions. The microstructures of specimens deformed in α+β region are shown in Fig.5a-5d, while the microstructures in β region are shown in Fig.5e-5h. In Fig.5(a) and 5(b), the microstructures indicate obvious morphological change of α phase from lamellar to equiaxed. The α lamellas were sheared during deformation and globularized by diffusional process, it may be considered as a type of dynamic recrystallisation[8]. It also can be observed that the globularization at higher strain rate is more obvious than that at lower strain rate. The degree of dynamic globularization increases with decreasing strain rate. The reason is that dynamic globularization has sufficient time to nucleate at lower strain rates. In Fig.5(c) and 5(d), we can see the distinct phase boundaries and fine grains, and the recrystallized grains are not discovered. But, the degree of the globularization increases with increasing deformed temperature. The reason is that higher deformation temperature the easier the occurrence of dynamic globularization. Therefore, the globurizing is the mechanism in α+β region.

In Fig.5(e) and 5(g), it can be seen that the grains become longer and the recrystallized grains are discovered in the grain boundaries. The degree of dynamic re-crystallization increases with increasing deformed temperature. Thus, the dynamic re-crystallization is the mechanism at the lower deformation rate in β region. The *Q* value in β region is lower than that in α+β region and the crystal structure is bcc which is easy for the slip system to move at temperatures above the transformation point. In Fig.5(f) and 5(h), the recrystallized grains are not discovered and the dynamic recovery is the mechanism at the higher deformation rate in β region

4. CONCLUSIONS

Near alpha titanium TA19 alloy has been studied during hot deformation both in the α+β region and β region. The flow stresses were correlated with strain rate and the temperature by the constitutive equation. The conclusions can be summarized as follows:

1) All of the flow curves exhibit an initial peak at the beginning of deformation process. Then, the flow stress decreases sharply to a near steady state, which all curves exhibit flow softening behavior.

2) The *Q* value obtained in the α+β region for TA19 was 586KJ/mol, and in the β region was 290KJ/mol.

3) In α+β region, dynamic re-crystallization easily occurred; in β region the dynamic re-crystallization is obvious at low strain rate and dynamic recovery is obvious at high strain rate.

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