Effect of Isothermal Annealing on the Microstructure and Impact Properties of TC10 Titanium Alloy

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Abstract: The microstructure and impact properties of TC10 titanium alloy bar after isothermal annealing are studied by metallographic microscope, SEM and impact properties test. The results show that there were two forms of α phases in the original microstructure of TC10 titanium alloy forging bar, one was primary equiaxied α phases, the other was secondary α phases. After the alloy was annealed with isothermal temperature, the content of the equiaxed α phases in the metallographic structure decreased with the increased of temperature, and disappeared after reaching the transformation point. While the number of platelet α in the structure increased with the increased of temperature, and the size increased. The impact toughness of the alloy shows a trend that first increases and then decreases with the increase of heating temperature. When the temperature exceeded the transformation point, the impact toughness decreases significantly. With the increase of heating temperature, the fracture morphology of the alloy mainly changes from a large number of relatively deep dimples to a few relatively shallow dimples, and dissociation steps appear. After the whole investigation, it can be concluded that the best heat treatment system in this experiment was 920℃×1.5h/FC→800℃×1.5h/AC+560℃×4h/AC, and the maximum impact toughness was 49.5 J/cm².

1. Introduction
TC10 titanium alloy is a two-phase titanium alloy rich in β-stabilizing elements, which is improved on the basis of TC4 titanium alloy[1-2]. It has excellent mechanical properties and heat resistance, as well as good oxidation resistance and corrosion resistance, and has been applied in the fields of aircraft fuselage, aero engine, nuclear reaction engineering and petroleum exploration, etc. In recent years, its application fields have been increasing, and its prospects are promising[3-4].

At present, the strengthening method of TC10 titanium alloy is mainly heat treatment. Zhu et al.[5] studied the effect of solution aging process on the microstructure and properties of TC10 titanium alloy. It has excellent mechanical properties and heat resistance, as well as good oxidation resistance and corrosion resistance, and has been applied in the fields of aircraft fuselage, aero engine, nuclear reaction engineering and petroleum exploration, etc. In recent years, its application fields have been increasing, and its prospects are promising[3-4].

Qi et al.[6] studied the effect of heat treatment temperature on the microstructure and properties of TC10 titanium alloy bar. The results show that when the hot forging deformation was 70%, the strength and plasticity of the bar had a good match. When the
solution temperature reached 800~810℃, the bar had good strength and plasticity, and its microstructure included equiaxed α and β phases.

However, there are few studies on isothermal annealing to strengthen TC10 titanium alloy. In this paper, by studying the influence of isothermal annealing process on the impact performances of TC10 titanium alloy, the best isothermal annealing process is explored, which provides some references for the production of this alloy.

2. Materials and Methods

The experimental raw materials was TC10 titanium alloy bar, whose composition was shown in Table 1. The measured transformation point was 940~945℃. The TC10 titanium alloy bar was cut into eight parts and annealed by four isothermal annealing processes at different temperatures (Table 2). After annealing, samples were taken from four groups of test materials and their impact properties was tested. The orientation of samples was L-direction.

The impact properties test was carried out by LF5255 testing machine, the metallographic structure was observed with the OLYMPUS GX71 metallographic microscope, and the fracture morphology of the impact properties samples was observed by Quanta scanning electron microscope.

Table 1. Composition of TC10 titanium alloy bar (wt. %)

|   | Al | V  | Sn | Fe | Cu | Ti |
|---|----|----|----|----|----|----|
|   | 5.7| 5.6| 2.3| 0.65| 0.65| Bal|

Table 2. Annealing process

| Process        | Samples No. | Heat treatment systems       |
|----------------|-------------|------------------------------|
| isothermal annealing | 1#          | 900℃×1.5h/FC→800℃×1.5h/AC+560℃×4h/AC * |
|                | 2#          | 920℃×1.5h/FC→800℃×1.5h/AC+560℃×4h/AC |
|                | 3#          | 940℃×1.5h/FC→800℃×1.5h/AC+560℃×4h/AC |
|                | 4#          | 960℃×1.5h/FC→800℃×1.5h/AC+560℃×4h/AC |

(*: 900℃×1.5h/FC→800℃×1.5h/AC means that the temperature was kept at 920℃ for 1.5h, and the furnace was cooled to 800℃ for 1.5h and then air-cooled.)

3. Results & Discussion

3.1 Metallographic structure

The original forged metallographic structure of TC10 titanium alloy bar was shown in Figure 1. The structure is a typical bimodal structure, in which there are two forms of α phases, one is primary α phase, which is evenly distributed on the matrix. The other is secondary α phase, which is mainly in the β transition structure. The original metallographic structure is composed of primary α phase and β transition (thin strips of secondary α phase, and the black background between secondary α phases is residual β).

Figure 1. Original forged metallographic structure

Figure 2 shows the metallographic structure of the alloy after isothermal annealing. Compared with the forged structure, the morphology of α phase in the structure has significant changes. Compared
with Figure 1, the metallographic structure in Figure 2a has an increased number of equiaxed α, and the size coarsened obviously. The metallographic structure has changed from a bimodal structure to an equiaxed structure, and a small amount of platelet α appeared. Compared with Figure 2a, the main changed in Figure 2b are the increase in size and quantity of platelet α. In Figure 2c, the structure is dominated by platelet α, with a very small amount of equiaxed α, and there are small strip α interlaced areas between some platelet α. In Figure 2d, coarse β grains and intact grain boundary α are shown, a large number of colonies are formed in part of the original β grain boundaries, and a large number of α plates grow parallel or staggered in the colonies.

Figure 2. Metallographic structure after isothermal annealing

3.2 Impact properties

The impact properties under different heat treatment systems were shown in Table 3. Within the temperature range selected in this experiment, with the increase of heating temperature, the impact toughness shows a trend of first increasing and then decreasing. After the transformation point is exceeded, the impact toughness decrease significantly, indicating that the impact toughness of equiaxed structure (Figure 2a, 2b) is better than that of platelet structure (Figure 2d). When the heat treatment temperature is reached 920℃, the impact toughness reaches the maximum value of 49.5 J/cm². The trend of impact absorption energy is consistent with that of impact toughness.

The energy absorbed by the alloy during the impact fracture process consists of two parts, one part is crack formation work, the other part is crack growth work. The grain size has a certain influence on the formation and propagation of cracks. When the heat treatment temperature is lower than the phase transition point (Figure 2a, 2b), the grain size of the alloy is smaller and the total area of the grain boundary is larger. If the crack growth through the grain boundary with complex dislocation structure, the energy consumption is greater, which leading to the improvement of impact toughness. At the same time, when the heating temperature is increased, the proportion of platelet α in the alloy increase (Figure 2b). Platelet structure could effectively improve the impact toughness of the alloy, resulting in the impact toughness of process 2# is higher than process 1#.

When the heating temperature is reached the transformation point (Figure 2c, 2d), a large amount of platelet α in the alloy are increased, and coarse β grains are formed. As the grain size increases, the energy consumption is reduced when the crack growth, and the impact toughness is reduced. Because the thickness of the α platelet in Figure 2d is smaller than that in Figure 2c. When the thickness of α platelet is smaller, the energy consumed by the crack through α platelet is less than the energy required.
for crack turning or bifurcating. At this time, the crack will propagate through α platelet, indicating that the proportion of crack growth work is relatively lower, and the impact toughness of process 4# decreases, which is consistent with the results in Table 3.

| Samples No. | Heat treatment systems | Impact absorption energy (J) | Impact toughness (J/cm²) |
|-------------|------------------------|------------------------------|--------------------------|
| 1#          | 900°C×1.5h/FC→800°C×1.5h/AC+560°C×4h/AC | 36                           | 46                       |
| 2#          | 920°C×1.5h/FC→800°C×1.5h/AC+560°C×4h/AC | 39                           | 49.5                     |
| 3#          | 940°C×1.5h/FC→800°C×1.5h/AC+560°C×4h/AC | 34.5                         | 42.5                     |
| 4#          | 960°C×1.5h/FC→800°C×1.5h/AC+560°C×4h/AC | 29                           | 36                       |

3.3 Fracture morphology

Figure 3 shows the microscopic fracture morphology under different heat treatment systems. Figure 3a and 3b have similar microscopic fracture morphologies which are mainly composed of dimples. The number of dimples are large and deep, indicating that the alloy has good toughness, the macroscopic performance is higher impact toughness, which is consistent with the results in Table 3. The microscopic morphology of the fracture in Figure 3c is river-like, with a small number of dimples and shallow depth, and a small number of dissociation steps, indicating that the toughness of the alloy has decreased. The fracture morphology in Figure 3d is mainly rock-like pattern, with a small number of shallow dimples and obvious dissociation steps. The morphology of grain interface is smooth, showing mixed fracture type of intergranular fracture and cleavage fracture. Therefore, the impact toughness in Figure 3d is the lowest. The overall trend is consistent with Table 3.

4.Conclusions

1. After isothermal annealing, the content of the equiaxed α phase in the metallographic structure decreased with the increased of temperature, and disappeared after reaching the transformation point. While the number of platelet α in the structure increases with the increased of temperature, and the size increased. When the heating temperature exceeded the transformation point, the structure was coarse β grains, and there were a lot of α platelet grew parallel or staggered in β grains.

2. The impact toughness of the alloy increased first and then decreased with the increased of heating temperature. When the temperature exceeded the transformation point, the impact toughness decreased...
significantly. The trend of impact absorption energy was consistent with that of impact toughness.

3. When the heating temperature was lower than the transformation point, the fracture morphology of the alloy was mainly composed of dimples, and the dimples were more and deeper. When the heating temperature was higher than the transformation point, the fracture morphology of the alloy was composed of a few shallow dimples and dissociation steps. The fracture was a mixture of intergranular fracture and cleavage fracture. After the whole investigation, it can be concluded that the best heat treatment system was 920℃×1.5h/FC→800℃×1.5h/AC+560℃×4h/AC, and the maximum impact toughness was 49.5 J/cm².

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