Abstract-This paper studies the effect of solution temperature on the microstructure and mechanical properties of TB10 titanium alloy bars. The results show that the microstructure is composed of β phase and primary α phase (α_p) when solution treatment is below the phase transition temperature. With the increase of the solution temperature, the β phase grain size in the microstructure increases, the thickness of the grain boundary decreases, and the number and size of the α_p phase decrease, so that the strength of the alloy decreases and the plasticity increases. When the solution treatment temperature is 800℃, the reticulated grain boundary α_p phase causes the plasticity to drop rapidly. When the solution treatment temperature is above the phase transition point, as the solution temperature rises, the β phase re-nucleates and grows, the grain size increases, the number of α_p phase decreases. The super-cooled β phase grains induce martensite phenomenon due to stress, which eventually causes the strength and plasticity to decrease.

1. Introduction
TB10 titanium alloy is a new type of material developed as the satellite and rocket connection belt. It is a kind of high-strength and high-toughness near-β titanium alloy with independent intellectual property rights. K_β=1.10, and Mo equivalent is 13.76 [1]. Because the total content of β-stabilizing elements in the alloy is near the critical concentration, so that the alloy has the performance characteristics of α+β and metastable β titanium alloy, which has high specific strength, good fracture toughness, high hardenability, and excellent thermal processing performance. It is an ideal structural material [2~4].

In order to obtain a good match between the strength and plasticity of the TB10 titanium alloy, the influence of the strengthening heat treatment system on the microstructure and mechanical properties of the alloy should be studied. Strengthening heat treatment includes two parts: solution and aging. Among them, the solution temperature has a greater influence on the phase composition, distribution, size and subsequent aging performance of the alloy [5]. This paper mainly studies the influence of solution temperature on the structure and properties of TB10 titanium alloy bars, which is helpful to formulate a reasonable heat treatment system.

2. Experimental
The experiment uses a Φ380 mm ingot smelted in a vacuum consumable electric arc furnace for three times. The ingot is billeted and forged at 1000~1100℃ to form a Φ170mm bar stock, and finally
rolled to $\Phi 63$mm at $900 \sim 1000 ^{\circ} C$. The composition of the bar is shown in Table 1. The heat treatment experiment is carried out in SX2-10-12 resistance furnace.

The bars are heat treated at 740$^{\circ}$C, 760$^{\circ}$C, 780$^{\circ}$C, 800$^{\circ}$C, 820$^{\circ}$C and 840$^{\circ}$C, which incubated for 30 minutes and then cooled in air. The microstructure was observed on NEOPHOT-2 optical microscope and CAMBRIDGE-2 scanning electron microscope.

Table 1. Chemical composition of ingot (mass fraction/%).

| Elements | Mo | V  | Cr  | Al  | Fe  | C   | N   | H   | O   | Ti   |
|----------|----|----|-----|-----|-----|-----|-----|-----|-----|------|
| Up       | 4.80 | 5.10 | 1.98 | 3.09 | 0.049 | 0.018 | 0.018 | 0.0045 | 0.11 | Bal. |
| Mid      | 4.91 | 5.04 | 2.05 | 3.08 | 0.048 | 0.015 | 0.015 | 0.0042 | 0.09 | Bal. |
| Down     | 4.86 | 5.08 | 2.01 | 3.10 | 0.050 | 0.021 | 0.014 | 0.0039 | 0.09 | Bal. |

3. Results and Discussion

3.1. Effect of solution temperature on microstructure

TB10 titanium alloy bars were kept at 740$^{\circ}$C, 760$^{\circ}$C, 780$^{\circ}$C, 800$^{\circ}$C, 820$^{\circ}$C and 840$^{\circ}$C for 30 minutes and then cooled in air. The microstructure is shown in Fig. 1.

![Fig. 1 Microstructure of TB10 titanium alloy at different solution temperature](image)

Using quenching metallographic method, the phase transition point temperature of the material is 810$^{\circ}$C. The microstructure of TB10 titanium alloy after solution treatment at the transformation point temperature is shown in Fig. 1 (a ~ d). When the solution temperature is 740$^{\circ}$C and 760$^{\circ}$C, due to the
precipitation of a large amount of $\alpha_p$ phase, it is difficult to observe obvious $\beta$ phase crystal grains from the metallographic photos, but part of the grain boundary $\alpha_p$ phase can be observed. When the solution temperature is 780°C, as the precipitation amount of the $\alpha_p$ phase decreases, the $\beta$ phase grains, the grain boundary $\alpha_p$ phase and the intragranular $\alpha_p$ phase can be clearly distinguished. The $\beta$ phase grains with grain size of 5~15μm are long strip or nearly oval shape. When the solution temperature is 800°C, the grain boundary becomes thinner, the $\beta$ phase grains appear polygonal, the grain size in 10~30μm is significantly increased and uneven, and the precipitation of $\alpha_p$ phase is significantly reduced. It can be seen from Fig. 1 (e) and (f) that the morphologies of the two are relatively similar. The $\beta$ phase grains in the microstructure re-nucleate and grow up, presenting a regular polygonal shape with a size of about 20~30μm. The amount of precipitation of the $\alpha_p$ phase in the crystal is significantly reduced.

Due to the small size of the grain boundary $\alpha_p$ phase and intragranular $\alpha_p$ phase of the TB10 titanium alloy, it is difficult to observe clearly in the metallographic microstructure photos. The structure of the alloy is analyzed by SEM after solution treatment at 740°C and 800°C (Fig. 2). By comparing Fig. 2(a) with (b), it can be seen that when the solution temperature is 740°C, the grain boundary thickness is larger, and a large number of strips, short rods or granular $\alpha_p$ phases are dispersed in the $\beta$ phase crystal grains. When the solution temperature is 800°C, the thickness of the grain boundary becomes smaller and the number of $\alpha_p$ phases in the $\beta$ phase grains decreases.

![Fig. 2 SEM photograph of TB10 titanium alloy at different solution temperature](image)

(a) 740°C  (b) 800°C

By observing the microstructure evolution of TB10 titanium alloy at different solution temperatures, it is found that the morphology and quantity of the $\alpha_p$ phase are significantly different. When the solution treatment is below the phase transition temperature, the $\alpha_p$ phases distributed in the grain boundaries and within the grain are in the form of strips, short rods or granules, and the number of $\alpha_p$ phases is large. The oval shape of $\beta$ phase becomes a polygon, and the number of $\alpha_p$ phases in the $\beta$ phase crystal grains in the form of strips, short rods or granules decreases.

3.2. Effect of solution temperature on mechanical properties

The mechanical properties of TB10 titanium alloy bars after air cooling at 740°C, 760°C, 780°C, 800°C, 820°C and 840°C for 30 min are shown in Fig. 3. It can be seen from Fig. 3(a) that as the solution temperature increases, the tensile strength and the yield strength decrease, but the rate of decrease is different. The decrease rate of tensile strength and yield strength between 740°C and 800°C is relatively large. With the increase of solution temperature, the decrease rate of tensile strength between 800°C and 840°C is relatively small. Between 800°C and 820°C the rate of decrease in yield strength increases rapidly during the period, and then the rate of decrease becomes smaller. The difference between the tensile strength and the yield strength increases with the increase of the solution temperature, and the difference rapidly expands to 195MPa at 820°C, which results in a phenomenon of low yield stress. Fig. 3 (b) show the changes in percentage elongation after fracture and percentage reduction of area with solution temperature. The trends of the two are similar. With the
increase of the solution temperature, the change curve increases first, drops rapidly at 780 °C to 800 °C, and finally drops after rising to 820 °C.

Fig. 3 Tensile properties of TB10 titanium alloy at different solution temperature
(a) Tensile strength and yield strength;
(b) Percentage elongation after fracture and percentage reduction of area

Research shows that the microstructure under solution treatment has three main influence factors on the mechanical properties of TB10 titanium alloy: (1) β phase grain size; (2) the distribution and size of the grain boundary α_p phase; (3) the number, distribution and size of the α_p phase inside the β phase grain [6~8]. For β titanium alloys, the main factors affecting the strength of the material are the number, distribution and size of the α_p phase inside the β phase grains. When the distributed small size α_p phase is large, the strength of the material is high, on the contrary, the strength of the material decreases. As the solution temperature increases, the decrease in tensile strength and yield strength are not synchronized. The re-dissolved α_p phase increases, and the super-saturation of the β phase increases. When the supersaturated β phase grains are subjected to stress, partial martensite transformation occurs, and the yield strength decreases. That is stress induced martensite transformation [9]. When the solution temperature is above the phase transition point, the α_p phase is completely re-dissolved, and the β phase grains re-nucleate and grow. It is precisely because the super-saturation of the β phase increases suddenly that the yield strength drops rapidly, so the difference between the yield strength and the yield strength gradually increases with the increase of the solution temperature.

Both percentage elongation after fracture after fracture and percentage reduction of area characterize the plasticity of TB10 titanium alloy [10~12], and their changing trends are roughly similar as the solution temperature increases. In the solution treatment below the phase transition temperature, as the solution temperature increases, the number of α_p phases decreases, the size becomes smaller, and the plasticity of the material increases. As the solution temperature rises to 800 °C, the grain boundaries α_p are connected to each other into a network, which separates the β phase grains, and finally leads to the greatest decrease in the plasticity of the material. When the solution temperature is above the phase transition point, the net-like grain boundary α_p phase disappears, and the plasticity increases. As the β phase grains grow larger, the plasticity decreases.

4. Conclusion
Based on the results and discussions presented above, the conclusions are obtained as below:

(1) TB10 titanium alloy is solution treated below the transformation point temperature, and the microstructure is composed of β phase and α_p phase. As the solution temperature increases, the number of α_p phases in the crystal decreases and the size decreases, while the grain size of β phase crystals increases, and the thickness of the grain boundary α_p phase decreases.
(2) As the solution temperature above the phase transition point increases, the number of α<sub>p</sub> phases in the crystal decreases, the β phase grains increase, and the tensile strength and yield strength of alloys are reduced. The super-cooled β phase grains induce martensite phenomenon due to stress.

(3) The changing trends of percentage elongation after fracture and percentage reduction of area are roughly similar as the solution temperature increases. When increasing the solution temperature, the amount of intragranular α<sub>p</sub> phase decreases, the plasticity increases, and the ordering phenomenon of grain boundary α<sub>p</sub> phase becomes more obvious. At 800℃, the intragranular α<sub>p</sub> phase and grain boundary α<sub>p</sub> are connected to each other into a network, the plasticity of the alloy is reduced. The plasticity of the material increases due to the destruction of the network grain boundary at 820℃. The β phase grain size increases sharply at 840℃, resulting in a decrease in the plasticity of the material.

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