Study on Effect of Composion on Mechanical Properties of Near α Type Ti-alloys for Ship

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Abstract: Based on the titanium alloys of Ti- Al-V-Mo and Ti-Al-Mo-Nb-Zr systems, a study on new types of titanium alloys with a near α-microstructure for the ships and warships is performed. It is shown that the strength of the Ti-Al-V-Mo alloys is better than that of the Ti-Al-Mo-Nb-Zr alloys but the plasticity of the former is poor. Adding Nb to Ti-Al-V-Mo system does not improve its ductility. The V element has obvious influence on strength, but cannot improve the strength of the alloy if the content of V exceeds 2%. A content of 2% Nb in Ti-Al-Mo-Nb-Zr system is capable of remarkably improving the plasticity and toughness, while a content of 1% Mo can increase the strength greatly. However, exceeding amount of Mo reduces strength and weldability. Although the Zr element is helpful to the plasticity at low temperature, this function is restricted by deformation.
Key Words: Ti-alloy, Mechanical properties, Alloying element

1. Introduction

It is well known that titanium alloy is being widely used in the aviation, space flight, military, and domestic industries.

Also, the alloy is a perfect candidate for manufacturing navigation aids such as ships, warships, submarines owing to its high strength, anti-fatigue, and fracture toughness, as well as good weld ability and anti-stress-corrosion, and a certain level of plasticity. [1]

At present, there are two titanium alloys that can be used for making pressure-resistant shells in ships and submarines: the Ti-6Al-2Nb-1Ta-0.8Mo alloy with a near α-microstructure and the Ti-6Al-4V ELI alloy with a α+β microstructure [2].

A Ti-6Al-3Nb-0.8Mo alloy has been developed by Luoyang Ship Material Research Institute, China, which is a mimic of the Ti-6Al-2Nb-1Ta-0.8Mo alloy with a near α-microstructure from U.S.A.

The research group in Shanghai Iron and Steel Research Institute has been studying the Ti-Al-V-Mo alloy system and the Ti-Al-Mo-Nb-Zr alloy system with a near α-microstructure for more than ten years, including their compositions, working processes, heat-treatments, and properties. As a result, a near α-type titanium alloy with independent knowledge property right is developed, which is able to meet the needs of the manufacturing ships and submarines.

2. Experiments and results

Based upon the Ti-Al-V-Mo and Ti-Al-Mo-Nb-Zr alloy systems, the preliminary studies, and the necessary properties, 4 alloys with different compositions are engineered for testing:

A: Ti-Al- Mo -2V-Nb
B: Ti-Al- Mo -3V
C: Ti-Al -Nb-Zr-1Mo
D: Ti-Al -Nb-Zr.

Alloys A and B belong to the Ti-Al-V-Mo system, and C and D fall in the Ti-Al-Mo -Nb-Zr system.

The aim of adding element V in the Ti-Al-V-Mo system is to study the effect of V on strength. The purpose of putting Nb-element is to improve plasticity and toughness.

The goal of appending Zr to the Ti-Al-Mo-Nb-Zr system is to increase weldabililty, strength, and low temperature properties.

Element Mo is contained in two systems, because of its distinctive strengthening effect on structural titanium alloys.

Quantity of the added elements is required to make all 4 alloys to form the near α-microstructure, because the titanium alloy with near α-microstructure can be used as a structural material and welded by various techniques. The welded part is not required to be heat-treated to stabilize its microstructure. Hence, it is suitable for applications in navigate manufacture.

It is known from the concentration fraction of various elements that all four alloys should be the titanium alloy with a near α-microstructure [3] and their stabilization coefficient K_β shall be smaller than 0.25 (Table1).

Table 1 Stabilization coefficient K_β for the 4 alloys

No.	**Alloy**	**K_β**
A	Ti-Al- Mo -2V-Nb	0.23
B	Ti-Al- Mo -3V	0.25
C	Ti-Al -Nb-Zr-1Mo	0.17
D	Ti-Al -Nb-Zr	0.07

The raw materials of 4 alloys are firstly pressed into electrodes. Then, they are made into the ingots, with diameter of 120 mm and weight of 10 kg, in a vacuum consumable furnace. Finally, the ingots are hot-rolled into wires with Φ 8.5 mm as the samples for testment.

The observations by an optical microscope show that entire 4 alloys consist of a near α-microstructure. Table 2 gives the measured β-transition temperatures T_{β}.

Table 2 β-transition temperatures for the 4 alloys

No.	**Alloy**	**T_β/℃**
A	Ti-Al- Mo -2V-Nb	980
B	Ti-Al- Mo -3V	965
C	Ti-Al -Nb-Zr-1Mo	＞995
D	Ti-Al -Nb-Zr	995

The 4 alloys are solution-treated at 905℃ ~ 1005℃ for 1 hr. and water-cooled, respectively. The alloys are then aged at 460℃ ~ 540℃ for 4 hr. and air-cooled, respectively.

After that, the mechanical properties of the alloys are tested at 20℃ and -70℃, respectively. The strength $\sigma_{0.2}$ and elongation δ_5 of the one set of the samples at 20 ℃ and -70℃ and show in Table 3 and 4, respectively.

Table 3 Strength $\sigma_{0.2}$ and elongation δ_5 measured at room temperature for the 4 alloys solution-treated at different temperatures and aged at 500℃

Property	**$\sigma_{0.2}$/MPa**			**δ_5 /%**		
Solution Temperature/℃	920	955	990	920	955	990
A	980	1040	1080	10.7	15.3	14.7
B	1015	1055	980	11.3	12.7	10.0
C	815	940	935	17.3	14.0	16.7
D	675	670	675	17.3	13.3	13.3

Table 4 Strength $\sigma_{0.2}$ and elongation δ_5 measured at low temperature for 4 alloys solution-treated at different temperatures and aged at 500℃

Property	$\sigma_{0.2}$(MPa)			δ_5 (%)		
Solution Temperature(℃)	920	955	990	920	955	990
A	1145	1240	1175	8.0	10.0	6.0
B	1300	1245	1130	8.7	9.3	6.0
C	1005	1115	1140	10.0	11.3	12.0
D	855	855	770	13.3	10.7	14.0

3. Discussion

It is seen from Table 3 and 4 that two alloys of the Ti-Al-V-Mo system have higher strength and poorer plasticity. The 2% V and Mo in alloy A may be the main cause of increasing strength. Adding element Nb in alloy A is not able to improve its plasticity. The remarkable enhancement of strength of alloy B is due to adding of element V. But, the strength of B alloy cannot be enhanced when V-content increases to 3 %. The strength of Ti-Al-V-Mo alloy system at low temperature is higher than that at room temperature, but the plasticity is on the contrary, indicating that low temperature plasticity of the Ti-Al-V-Mo alloy system is poor, because there are more content of stable element, the higher stabilization coefficient K_β (Table 1), and the lower β-transition temperature in the system, leading to large reduction of plasticity as the solution temperature is higher than 950℃. The A and B alloys are treated at 1005 ℃ for 1h, water-quenched, treated at 500 ℃ for 4h, and air-cooled. The observations by an optical microscope show that two alloys consisting of aged martensite, with the microstructure in the B alloy being coarse. It is difficult for sliding to pass across the incoherent α-grain boundaries and martensite interfaces where cracks and holes form easily, resulting to poor plasticity.

From Table 3 and 4, it can be found that the strength of the Ti-Al-Mo-Nb-Zr system is lower than that of Ti-Al-V-Mo system, as predicated during previous engineering phase. Element Nb of stable β and neutral element Zr are weak elements of strengthening. After being heat treated, the Ti-Al-Mo-Nb-Zr system alloys have higher strength at low temperature strength is higher than at room temperature, similar to the Ti-Al-V-Mo system. And the low temperature plasticity of Ti-Al-Mo-Nb-Zr system is also higher than the room temperature plasticity. It has been suggested that element Zr can be fully solid-dissolved into α-Ti and β-Ti and has the same atomic structure and unfilled electronic shells as appear on Ti, creating a smaller deformation of crystal lattice. Moreover, element Zr is helpful to the twin-deformation of Ti at low temperature and able to make the alloys keep a higher elongation and toughness [4]. A remarkable effect of Zr on mechanical properties of the Ti-Al-Mo-Nb-Zr system at low temperature may be seen from Table 4.

The strength of the C alloy in the Ti-Al-Mo-Nb-Zr system which contains 1% Mo is 100 MPa higher than that of the D alloy without Mo, showing an evident strengthening effect of 1 % Mo. However, no strengthening effect is observed when the Mo-content increased to 2% in the Ti-Al-Mo-Nb-Zr system. In addition, when Nb element is taken out of the Ti-Al-Mo-Nb-Zr system, there is a 90% decrease of plasticity and its strength does not change, meaning that Nb-element is capable of improving the plasticity of the alloys strongly. For example, the elongation δ_5 of the C alloy at room temperature is up to 17.3% and still around 10% even at low temperature.

Also, the present study shows that the strength of the two-alloy system is not sensitive to the solution-temperature and aging temperature, i.e. the strength is not sensitive to the microstructures. The elongation and rupture characteristics are largely related to different heat-treatment. In other words, the plasticity depends on the microstructures apparently, which agrees with the result given in the study of effect of microstructures on the mechanical properties of Ti-6Al-2Nb-1Ta-0.8Mo alloy by Lin et al. [5,6]

4. Summary

(1)The strength of the Ti-Al-V-Mo system titanium alloy with a near α-microstructure is better than that of the Ti-Al-Mo-Nb-Zr system titanium alloy with a near α-microstructure. The plasticity of the Ti-Al-V-Mo system is poorer and cannot be improved by adding Nb. The strength is strongly affected by V-element and is not increased when the V-content exceeds 2%.

(2)A considerable increase of plasticity and toughness occurs due to the adding of Nb in the Ti-Al-Mo-Nb-Zr system. The strength can largely increase owing to adding 1%Mo but sharply reduced by further increasing Mo. Although element Zr is able to improve the low temperature plasticity, the measured properties for the hot-rolled plates indicates small improvement only, meaning that the effect of Zr on low temperature properties may be restricted by some other alloying elements. In addition, the experiments show that the effect of Zr on low temperature properties is related to the degree of deformation of the materials, because there are a large amount of defects and extended internal stress and texture in the hot-rolled plates.

(3)The C alloy in the Ti-Al-Mo-Nb-Zr system is a perfect candidate of titanium alloy for manufacturing ships and warships due to its good basic properties.

(4)Based on the C alloy in the Ti-Al-Mo-Nb-Zr system, a new type of titanium alloy with a new α-microstructure is developed. Its main properties are as following: $\sigma_{0.2} \geqslant$ 784MPa, $\sigma_b \geqslant$850MPa, $\delta_5 \geqslant$12%, $a_k \geqslant$588kJ/mm^2, $k_{Ic} \geqslant$93.0MPa·m$^{1/2}$, welding coefficient ⩾0.9, and cold-bent angle α⩾90° (d=10a). It is shown from industrial tests that the new type near α-microstructure titanium alloy has good comprehensive properties, especially mechanical properties at room and low temperatures, and is best suited for the applications in ships, warships, and pressure-resistant shells in submarines. The alloy has been patented in China, with independent knowledge property right, and is a recommendable structural material.

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