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EFFECT OF ANNEALING TEMPERATURE ON MICROSTRUCTURE AND PROPERTIES OF Ti 3Al-5Fe-1Cr TITANIUM ALLOY GOLF CLUB

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Titanium alloy is a common material of golf clubs. Ti-3Al-1-5Fe-1Cr titanium alloy is a relatively successful golf club material because it enhances the anti-elasticity of golf clubs. The Ti-3Al-1,5Fe-1Cr dual phase titanium alloy was studied. The microstructure and mechanical properties of the alloy after annealing treatment were studied. The effects of annealing treatment on the microstructure, hardness, strength, plasticity and toughness of the alloy were clarified. After annealing treatment, the microstructure of the alloy is composed of cluster-like staggered lamellar α phase and β phase. When the annealing temperature is 850 °C, the hardness of the alloy is the highest 447 HV, the tensile strength is the highest 958 MPa, and the elongation after fracture is 16 %.

Keywords: Ti 3Al-5Fe-1Cr titanium alloy, annealing, phase, microstructure, mechanical properties

INTRODUCTION

Golf club is the basic equipment in golf, which is composed of ball head, rod body and grip. According to the different purposes of the ball bar, and the ball bar is designed into different rod head shape and rod length, Ti 3Al-5Fe-1Cr titanium alloy as a kind of titanium alloy, not only take into account the advantages of titanium alloy material, but also increase the rebound, is a more successful golf club material.

Dual-phase titanium alloy has been widely used in ships, military industry, oil exploitation, medical equipment and sporting goods due to its excellent comprehensive mechanical properties [1-3]. At the same time, the dual-phase titanium alloy has excellent hardenability and can be strengthened by heat treatment to obtain better mechanical properties. The heat treatment process will have different effects on the microstructure of titanium alloy, which will affect the strength, plasticity, hardness and impact toughness of the alloy [4-5]. In addition, the microstructure evolution and mechanical properties of dual-phase titanium alloys with different compositions show different heat treatment responses. Ti-3Al-1,5Fe-1Cr is a new type of dual-phase titanium alloy, and it is of great significance to study its different heat treatment. The Ti-3Al-1,5Fe-1Cr alloy was annealed at different temperatures, and the microstructure of the alloy under different heat treatment conditions was studied.

Materials and methods

The material of this experiment is Ti-3Al-1,5Fe-1Cr titanium alloy. The Mo equivalent of this alloy is 5.95. According to the content of Mo equivalent, it is judged to be a dual-phase titanium alloy. The experimental steel was annealed by box-type resistance furnace. The annealing holding temperature was 810,830,860,910 and 970 °C, and the annealing time was 2h. The microstructure of the experimental steel was observed by metallographic microscope. The corrosive agent was 3 % nitric acid alcohol solution. The mechanical properties of experimental steels in different states were tested on 5105 microcomputer controlled electronic universal testing machine.

Experimental results and discussion

The microstructure of the alloy was analyzed by Electron Back Scatter Diffraction, and the resolution rate of Electron Back Scatter Diffraction (EBSD) images was more than 95 %. The EBSD images of the alloy under different annealing conditions are shown in Figure1. After annealing treatment, the microstructure image of the Ti-3Al-1,5Fe-1Cr alloy is composed of a cluster of interlaced lamellar α phase and β phase. From the diagram, it can be seen that a large number of primary α phases grow near and within the β grain boundary after the annealing treatment in the dual-phase region to form α phase and grain boundary α phase growing from the grain boundary to the grain and no secondary α phase is observed. The size of the α phase in the structure is relatively slender, and a large number of α sheets with the same orientation converge to form α bundles. Overall, the structure is similar to the basket-weave structure with better impact toughness. The microstructure after annealing in the single-phase region, due to the high annealing temperature, the grain boundary α

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Figure 1 EBSD images of alloys under different annealing conditions

Table 1 **Mechanical properties of Ti alloy annealed at different temperatures**

Number	Tempering temperature	Hardness/ HV	R_v/ MPa	R_m/ MPa	Elongation/%	impact work
1	800	391	862	932	15,7	83,7
2	820	412	869	941	15,3	85,3
3	850	447	878	958	16,0	86,9
4	870	427	863	943	13,4	83,6
5	900	404	852	934	10,7	80,4
6	920	386	844	919	8,9	78,5
7	950	369	833	906	7,1	64,9
8	980	358	821	895	5,8	56,7

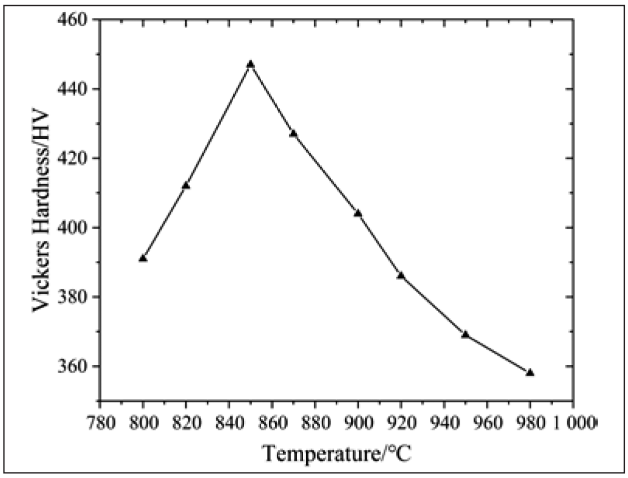

Figure 2 Effect of annealing temperature on hardness of experimental titanium alloy

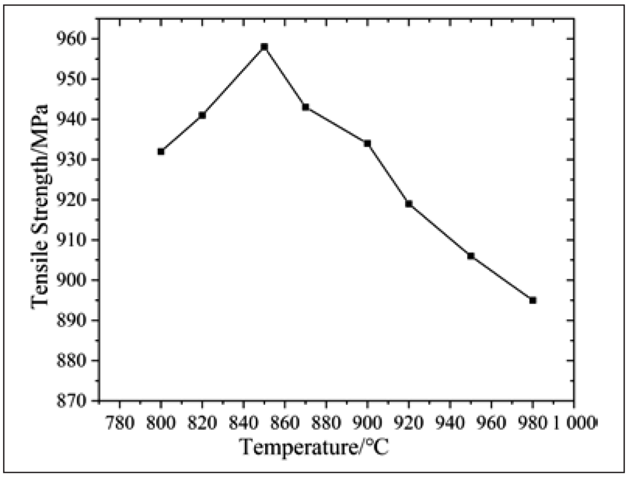

Figure 3 Effect of annealing temperature on tensile strength of experimental titanium alloy

phase is too coarse, and the α lamellae inside the β grains are significantly coarsened. A large number of α-bundles are destroyed, resulting in a decrease in the volume fraction of α-bundles, and the orientation difference between lamellas is increasing. At the same time, the volume fraction of β-phase is also significantly increased, indicating that higher annealing temperature is beneficial to the growth of α-phase and the retention of β-phase in the alloy.

During the annealing process, both the annealing time and temperature affect the properties of the material. In general, the best ratio can be obtained by controlling the parameters. The mechanical properties of the experimental titanium-alloy at different annealing temperatures are shown in Table 1.

The hardness of the alloy was evaluated by Vickers hardness method. The Vickers hardness curves of the experimental titanium alloy at different annealing temperatures are shown in Figure 2. In order to avoid the experimental error, the hardness measurement was carried out at different quadrants of the plane of the sample block. The hardness of the rolled alloy was 405 HV, and the hardness did not change much. The change trend of the hardness was similar to the strength trend. The hardness value of the alloy is evenly distributed and the defects are less.

Figure 3 and Figure 4 show the relationship between tempering temperature and tensile strength and yield strength. The basic law is as follows: with the increase of tempering temperature, the change law of first increase and then decrease is presented. After annealing in the dual phase region, the elongation of the alloy after fracture is increased to a certain extent compared with that of the rolled state, and the tensile strength and yield strength of the alloy are improved to a certain extent. After annealing in the single-phase region, the plasticity of the alloy is greatly reduced compared with the rolled state and the strength is also reduced. Compared with the annealing temperature at 800 °C and 820 °C, the strength of the alloy is improved when the plasticity is very close at 850 °C, and the tensile strength of the alloy is up to 958 MPa. In the annealing process of the single-phase region, the elongation of the alloy after fracture decreases especially, especially after the annealing process at 980 °C, the plasticity of the alloy is reduced to 5,6 % compared with that of the rolled state.

Figure 5 is the effect of tempering temperature on elongation. It can be seen that with the increase of annealing temperature, the elongation decreases first and then increases and then decreases. At 850 °C, the elongation is 15,9 %. Compared with the adjacent data, the value is the highest, but the change of section shrinkage is more obvious.

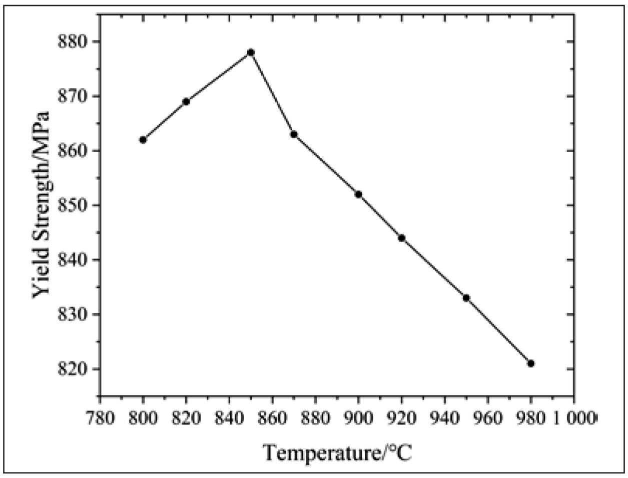

Figure 4 Effect of annealing temperature on yield strength of experimental titanium alloy

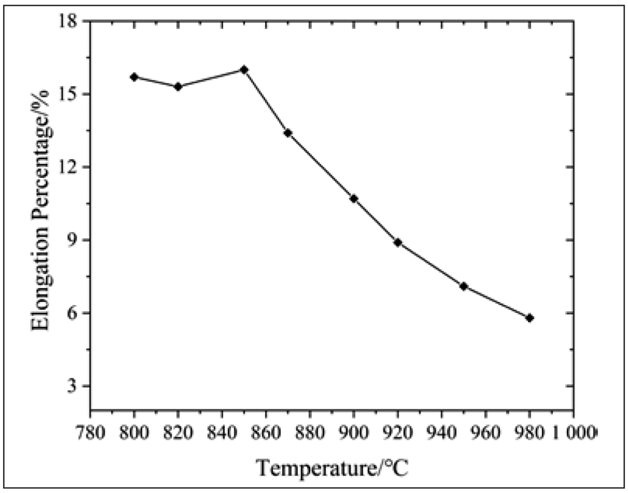

Figure 5 Effect of annealing temperature on the elongation of experimental titanium alloy

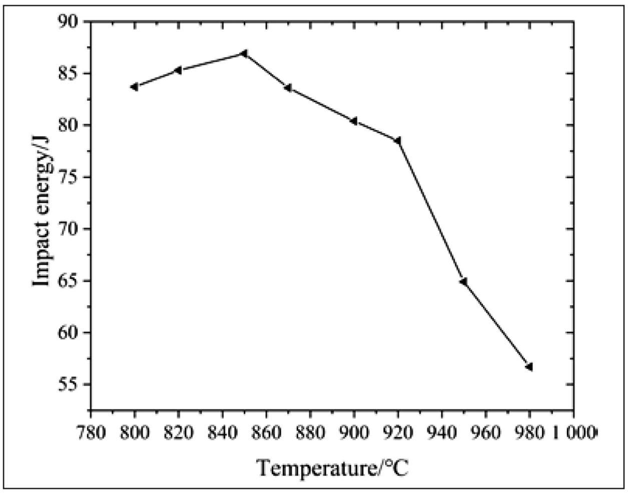

Figure 6 Effect of annealing temperature on impact toughness of experimental titanium alloy

The impact energy reflects the ability of the material to resist deformation and failure under impact load, and its size reflects the impact toughness of the material. As shown in Figure 6, it can be seen from Figure 6 that after annealing at five different temperatures, the impact toughness of the alloy at the annealing temperature in the dual-phase region is improved. When the annealing temperature continues to rise to the single-phase region, the grains grow rapidly, the structure is difficult to intercept the crack propagation, and the impact toughness value tends to decrease. Among the five different temperature annealing processes, the annealing treatment at 850 °C in the dual phase region makes the impact toughness of the alloy reach the highest value.

The results show that the Rockwell hardness, tensile strength, yield strength, impact toughness and elongation of the tested steel after tempering do not increase or decrease monotonously with the increase of annealing temperature, but the maximum or minimum values of each performance appear at 850 °C.

CONCLUSION

After annealing treatment, the microstructure of the alloy is a cluster of interlaced lamellar α phase and β phase. With the increase of annealing temperature, the length of α layer decreases and the thickness increases. For the alloy after annealing treatment, with the increase of annealing temperature, the hardness and strength of the alloy increase first and then decrease. When the annealing temperature enters the single-phase region, the plasticity and toughness of the alloy decrease significantly.

The annealing temperature has a significant effect on the mechanical properties of the test titanium alloy. In the annealing temperature range of 800 ~ 980 °C, the hardness, yield strength and tensile strength of the test titanium alloy remain high. The change trend of mechanical properties of the test steel is mainly divided into two stages. With the increase of tempering temperature, it increases first and then decreases slowly. The best annealing treatment process of the alloy is 850 °C / 2 h. The hardness is the highest 447 HV, the tensile strength is the highest 958 MPa and the elongation is 16 %. This study has a certain effect on the development of golf club materials.

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Note: The responsible translator for English language is J.Y. Zhang - Changchun Normal University, China.