Transactions of the Materials Research Society of Japan. Vol. 20

Materials Design of Recyclable Titanium-Aluminum Alloys

Takashi Ikeda and Masafumi Maeda
Institute of Industrial Science, The University of Tokyo
7-22-1 Roppongi, Minato, Tokyo 106, Japan

Titanium metal is not extensively recycled because it has an extremely strong affinity for oxygen, and hence is easily contaminated. If oxygen in molten titanium could be removed, the recycling of titanium would be possible on a much larger scale. In the present study, the removal of oxygen from molten titanium was attempted by adding aluminum while undergoing melting by an electron beam. The results indicate that oxygen in titanium-aluminum alloys could be reduced easily from 500 to 26 mass ppm in ten minutes. In addition, the effect of aluminum and oxygen content on the mechanical properties of titanium-aluminum alloys was investigated by Vickers hardness testing and tensile strength testing at room temperature and at 873K.

1. Introduction

Titanium and titanium alloys are attractive materials owing to their superior properties such as high strength, light weight and high corrosion resistance. Although the material is currently produced by a energy intensive process, there is no large-scale recycling process for titanium and its alloys, because of its extremely strong affinity for oxygen. If the removal of oxygen from molten titanium and its alloys were possible, recycling of these materials would be feasible on a larger scale.

In the present study, the development of a deoxidation process together with titanium-aluminum alloys suitable for the removal of oxygen have been proposed and examined to enable its efficient recycling. The process consists of a plasma arc melting followed by an electron beam melting technique. The mechanism by which deoxidation occurs was studied and the mechanical properties of the resulting Ti-Al alloys were also investigated.

The alloy composition range and phase structure examined in the study are shown below in Figure 1. The alloys contained 5 - 15 mass % aluminum and consisting mainly of two phases, α and α_2.

2. Experiment

A schematic of the electron beam furnace employed in the study is shown in Figure 2. The chamber, crucible, electron beam gun and turbo molecular pump are all water-cooled. The maximum power of the electron beam gun is about 8kW. The chamber is evacuated by using a rotary pump and two turbo molecular pumps. The sample is melted in a water cooled copper crucible of dimension 40x40mm under a total pressure of about 10^{-7}atm.

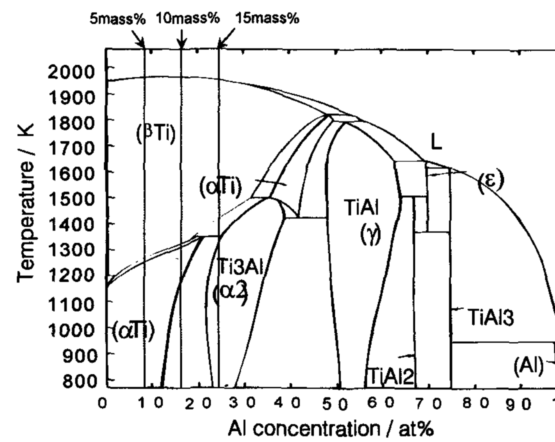

Fig.1 Ti-Al phase diagram.

After each experiment, the sample was chemically analyzed for oxygen, titanium and aluminum. Oxygen was analyzed by the fusion technique under a helium carrier, detected by infrared absorption (LECO). Aluminum and titanium were determined by inductively coupled plasma spectroscopy.

3. Results and Discussion

3.1 Removal of oxygen from molten titanium alloys.

The titanium, aluminum, oxygen and nitrogen contents are shown in Figure 3 and 4, as a function of melting time. Aluminum was added to compensate for the evaporation during melting of Ti-25 mass%Al. As shown in Figure 3, the composition of the alloy could be kept almost constant using this technique. This indicates that the composition can be controlled in the remelting practice of titanium scrap.

Figure 4 shows that the oxygen content was decreased from 500 mass ppm to 26 mass ppm within 10 min in the same experiment as Figure 2

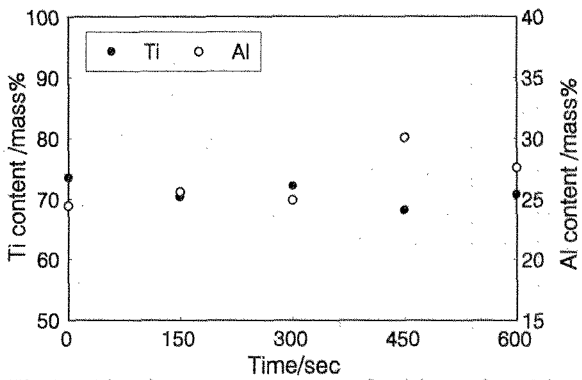

Fig.3 Aluminum content as a function of melting time

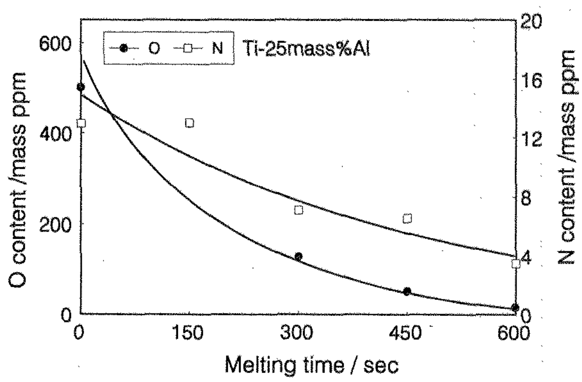

Fig. 4 Change of oxygen and nitrogen in Ti-25mass%Al-0.

The removal of oxygen may be written as follows:

$$xAl + y/2\ O_2 = Al_xO_y. \qquad (1)$$

The vapor pressure of the aluminum oxide gas (AlO, Al_2O, Al_2O_2, AlO_2) can be expressed as a function of the partial pressure of the oxygen[1]. Most likely Al_2O is the species by which oxygen is removed from the melt under the conditions of temperature and atmosphere present in the experiment.

3.2 Microstructure of the deoxidized titanium alloys

3.2.1 Effects of oxygen content on microstructure.

Figure 5 shows the microstructures obtained after heat treatment of Ti-Al containing 100 and 2400ppm

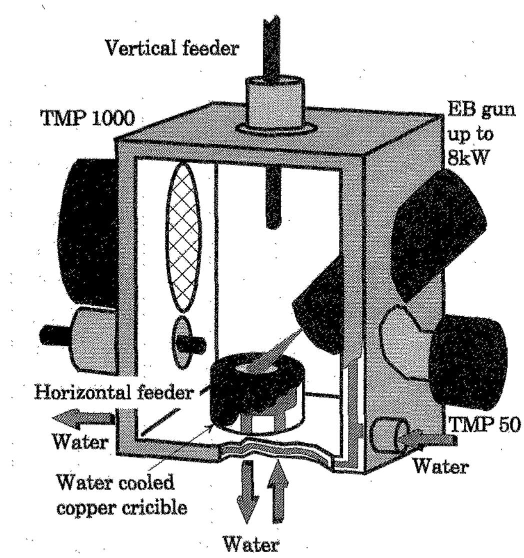

Fig.2 Schematics of electron beam furnace.

oxygen - left and right photomicrographs, respectively. The grain size was about 300 to 500μm. As can be seen the lamella structure of the α and α_2 phases is present. Comparing the two composition, the α_2 layer was thicker in the specimen of higher oxygen content.

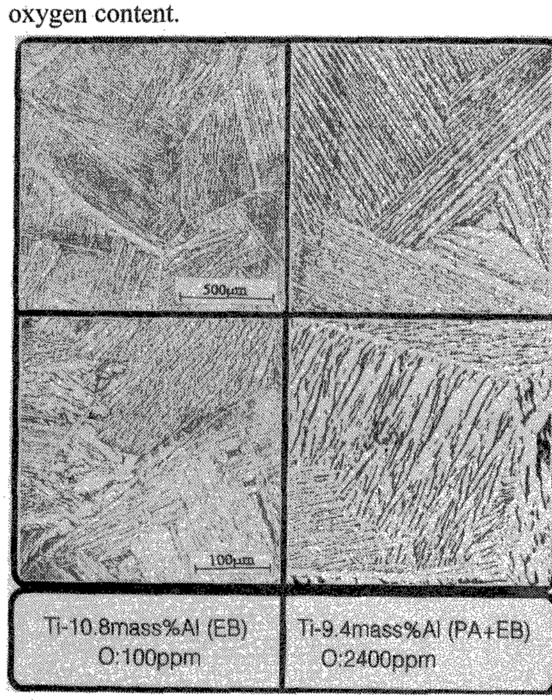

Fig.5 Microstructure of Ti-Al after heat treatment

3.3 Mechanical properties

3.3.1 Vickers hardness testing

Figure 6 shows the influence of oxygen content on Micro-Vickers hardness of α and α_2 phases. As can be seen, the hardness of α_2 increased with increasing oxygen content where as, that of α phase remained essentially unchanged.

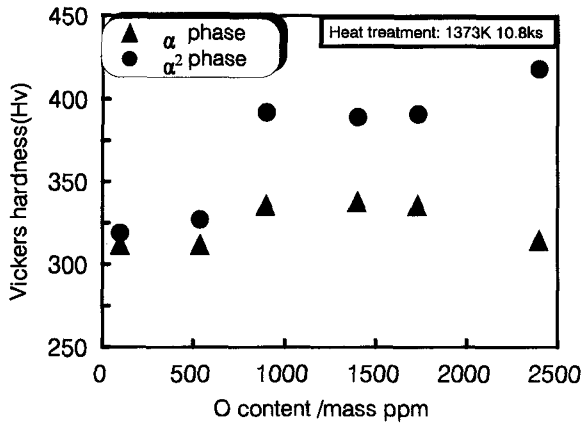

Fig.6 Effect of oxygen content on Micro Vickers hardness of α and α_2 phases.

3.3.2 Tensile testing.

The samples for tensile testing were prepared by the wire cut discharge technique. The size of test pieces was 3x3x14mm in gage length. Heat treatment was carried out at 1373K for 3h prior to conducting the test. The tensile tests were conducted at room temperature and at 873K after heat treatment.

The stress-strain curves obtained for the tests conducted at room temperature are shown in Figure 7. A failure stress of 410MPa and strain of 0.23% were measured for the specimen of 100 mass ppm oxygen. Both stress and strain decreased to 160MPa and 0.12%, respectively, with increasing oxygen content to 2400 mass ppm.

The results for the samples tested at 873K are shown in Figure 8. As can be seen, the stress and strain increased with increasing temperature to 710MPa and 15.6%, respectively, for the alloy containing 100 mass ppm oxygen and to 375MPa, and 8.3%, respectively, for the composition containing 2400 ppm oxygen.

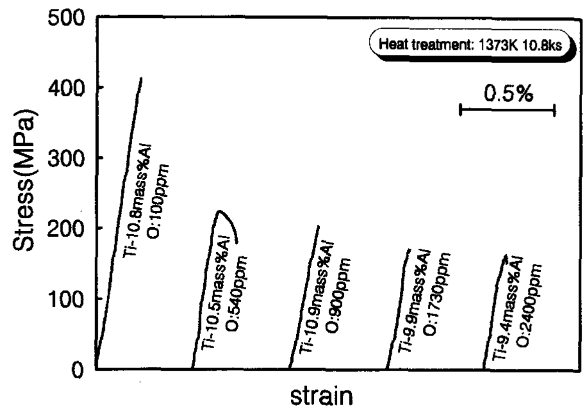

Fig. 7 Effects of oxygen content on Stress-strain curve at room temperature.

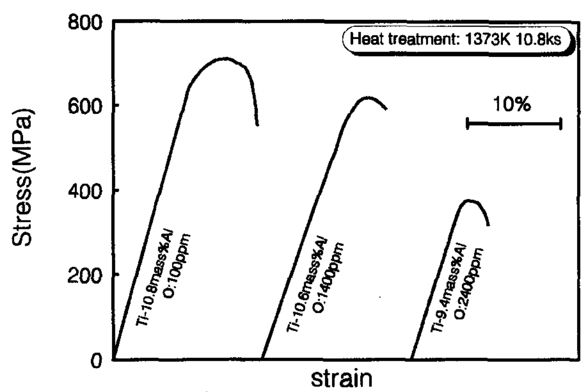

Fig.8 Effects of oxygen content on Stress-strain curve at 873K.

4. Conclusions

Oxygen in titanium alloy could be controlled by applying the electron beam furnace and the plasma arc furnace.

Vickers hardness of α_2 increased with increasing oxygen content where as, that of α phase remained essentially unchanged........

A failure stress of 410MPa and strain of 0.23% were measured for the specimen of 100 mass ppm oxygen. Both stress and strain decreased to 160MPa and 0.12%, respectively, with increasing oxygen content to 2400 mass ppm

References

1)T.Yahata, T.Ikeda and M.Maeda: Met.Trans. B, vol. 24B, 1993, pp.599-604