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A Study on the Mechanical Properties of Ti-8Ta-3Nb Alloy for Biomaterials

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Ti-8Ta-3Nb has been developed as a new biomaterial. The experimental specimens are as-cast and forged Ti-8Ta-3Nb alloys. Treatment in a solution, ranging from 760 to 960℃ has carried out. The microstructural research has carried out after the solution treatment and the hardness was measured. The specific heat and the length variations of Ti-8Ta-3Nb were also measured. The optimum temperature for the solution heat treatment of Ti-8Ta-3Nb was found to be 880℃. This was based on the mechanical properties and the volume fraction of α phase and their phases shown from the results of the solution heat treatment. From the results, the β transition temperature of Ti-8Ta-3Nb was found to be between 860℃ and 880℃.

Key Words : Specific Heat, β-Transition Temperature (T_β), Ti Alloy, Hardness, Heat Treatment Solution

1. Introduction

Ti alloys, whose specific strength, corrosion resistance, mechanical properties and fracture characteristics are good, are usually used in the space and chemical industries. Ti alloys also have good merits in biocompatibility and have been the focus in the creation of biomaterials.

The representative $\alpha+\beta$ alloy, Ti-6Al-4V alloy, has been broadly used as it is better than pure Ti in tensile strength, but has bioadhesion characteristic, like pure Ti ; good specific strength and good corrosion resistance. Recently, a lot of research has been undertaken in order to develop new biomaterials that will replace Al and V, since reports on their biosafety are questionable (Lione, 1983 ; Gail et al., 1986 ; Agarwal et al., 1996).

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Okazaki et al. have developed the biomaterials-Ti-15Zr-4Nb-4Ta-0.2Pd-0.05N-0.2O and Ti-15Sn-4Nb-2Ta-0.2Pd-0.2O alloys, which don't include Al or V, and have studied their possible applications since the beginning of the1990's (Okazaki et al., 1996 ; Rao et al., 1997).

Niinomi et al. have studied the properties of many biomedical Ti alloys as well as Ti-6Al-7Nb including Nb and excepting V element because of its cytotoxicity (Niinom, 1998).

According to studies on the bio-safety of biomaterials, V and Co are classified in a material class having cytotoxicity ; Mo, Al, and stainless steel 316L, as the capsule material class forming protective membranes ; while Ti, Ti alloys, Nb, Ta, Zr, and Pt as the so-called vital material class having a very good biocompatibility.

Nowadays, it is necessary to develop new biomaterials which have better biocompatibility characteristics than the widely used Cr-Co and SUS 316L (Evans et al., 1986 ; Bordji et al., 1996).

Therefore, as part of the developing efforts, this study attempts to research the physical and thermal properties of the new biomaterial-Ti-8Ta-3Nb, by excluding Al and V, which are not so biocompatible, from Ti-6Al-4V, whilst adding Ta and Nb.

2. Experimental Method

2.1 Specimen preparation

The Ti-8Ta-3Nb alloy was melted three times using an electrode not to be consumed and was made into small rods. The rods were then connected forming electrodes to be consumed. The as-cast specimens were made through the consumable VAR process. Remelting was carried out in a furnace filled with Ar, to make uniform alloys with the electrode, not to be consumed. Then the cylindrical rods were made. The chemical composition of the alloy in wt.% was as follows: Ta-7.23, Nb-3.22, Ti-balance. The homogenizing treatment was carried out at 1050℃ for 24 hours.

2.2 Heat treatment

The cylindrical specimens of length 6 mm, and diameter 5 mm, were machined from a Ti-8Ta-3Nb alloy on which the homogenizing treatment was carried out. The Ti-8Ta-3Nb underwent two primary processes. The first, the forging process, was at 950℃ followed by a homogenizing treatment whereby same sized specimens were made, similar to the as-cast specimens.

Solution heat treatment using the same method was carried out on both the as-cast specimens and the specimens from the forging process. The variation in hardness as a result of the solution heat treatment, the phase volume fraction according to temperature, and the β transition temperature were all verified.

The solution heat treatment was carried out whilst increasing the temperature by 20℃ each hour, from 760℃ up to 960℃. The specimens were then cooled using cold water.

The microstructure and phase analysis of the specimens, on which the solution heat treatment was carried out, was examined using SEM.

Rockwell (B) hardness was measured in order to examine the mechanical properties.

The optimal temperature of the solution heat treatment was determined through observation and measured values.

2.3 Measurement of specific heat and length variation

The specific heat of the Ti-8Ta-3Nb alloy that has undergone forging process, was measured in accordance with an increase of temperature, up to 1200℃. Specimens used for the specific heat measurement were in the form of a circular sheet with a diameter of 5 mm and height of 0.5 mm.

In order to measure the specific heat, the variation in the specific heat between in the previous and the latter β transition temperature temperature was expressed using a numerical formula.

The measurement in the length variation was also carried out on the Ti-8Ta-3Nb that underwent the forging process. The specimens used for length measurement were 3 mm in diameter and 10 mm in height. The length variation was measured according to the increase of temperature up to 1100℃.

The study thereby was able to verify how the β transition temperature, through variations in hardness, and microstructure were related to the length variation according to the temperature.

3. Results and Discussion

3.1 Heat treatment

The hardness of the as-cast specimen and the forged specimen were measured using a Rockwell hardness tester, after the solution heat.

Figure 1 shows the hardness test result after the solution heat treatment. The hardness results

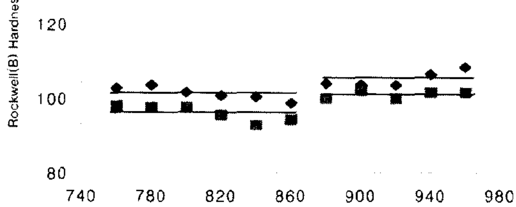

Fig. 1 Hardness test result after the solution heat treatment

show two typical values ; one group is 760℃ to 860℃, and the other values slightly increased. This trend shows as a result of the increment of volume fraction of the β phase transition, accompanying the martensite volume change by the solution heat treatment. Comparing these results, one can hypothesize that the β transition temperature is around 860℃.

Throughout the experiment, the hardness of as-cast specimen is higher than the forged specimens. However, the hardness of both the as-cast and forged specimens abruptly increased above 880℃. It can be therefore inferred that the forging process do not effect the β transition temperature of Ti-8Ta-3Nb specimens.

Figure 2 shows the volume fraction of α phase for Ti-8Ta-3Nb in as-cast and forged specimens. It shows that the α phase volume fraction for as-cast specimen is more than that of a forged specimen, according to an increase in temperature.

That is, the β phase volume fraction of the forged specimen is more than that of the as-cast specimen. Therefore, it may be concluded that the hardness of the forged specimen is higher than that of the as-cast specimen as a result of the increase in the amount of induced martensite by stress and thermally induced martensite, the deformation process after heat treatment.

Figures 3 and 4 depict the microstructures of the specimens that have cooled after solution heat treatment applied in 20℃ increments starting at 760℃, up to 960℃. The microstructures are observed using SEM images (S-2400). The

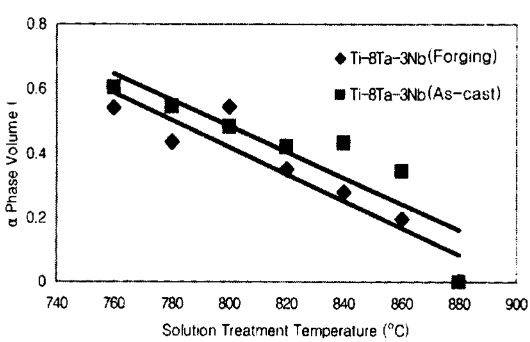

Fig. 2 α phase volume fraction for Ti-8Ta-3Nb in as-cast and forged specimens

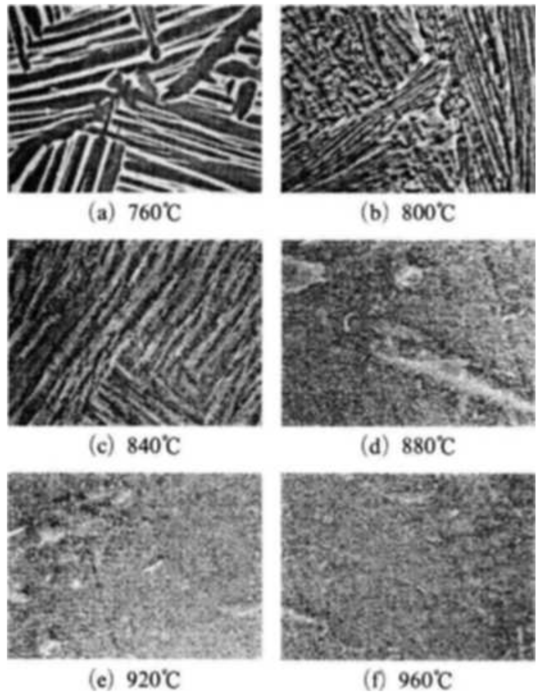

Fig. 3 SEM image(X2000) of Ti-8Ta-3Nb(as-cast) after solution treatment

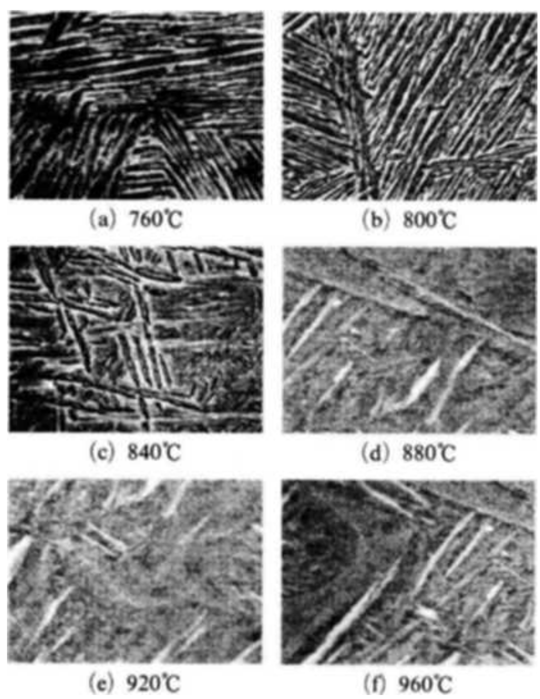

Fig. 4 SEM image (X2000) of Ti-8Ta-3Nb (Forging) after solution treatment

microstructure of Ti-8Ta-3Nb that has undergone the solution heat treatment at 880℃, is martensite which doesn't have an β phase because the β single phase domain is within the temperature range above 880℃. The martensite changed from the β phase in the cooling process, after the solution heat treatment.

It was found that the α phase volume fraction decreased and the α phase like widmanstatten or acicular decreased and was refined in accordance with an increase in the temperature of the solution heat treatment below 880℃. The α phase of the Ti-8Ta-3Nb was also further refined in contrast to the Ti-13Zr-13Nb, when the temperature increases (Min, 1997).

Figures 3 and 4 illustrate that the β transition temperature of Ti-8Ta-3Nb was between 860℃ and 880℃. Through the solution heat treatment, it was found that the β transition temperature of Ti-8Ta-3Nb in an as-cast specimen was equal to that of a forged specimen.

The optimum temperature of the solution heat treatment was calculated to be 880℃, considering the mechanical properties and the α phase volume fraction and their phases. (Prasad et al., 1998).

3.2 Results of specific heat and length variation

Figure 5 highlights a variation in the specific heat (SAT 449C Jupiter) of the Ti-8Ta-3Nb, below the β transition temperature. Fig. 6 depicts variation in the specific heat of the Ti-8Ta-3Nb, from the β transition temperature up to 1200℃.

Figures 5 and 6 show the specific heat of Ti-8Ta-3Nb increases in two steps, on the basis of the β transition temperature. From the result, the microstructural transformation was found to bring the change of the specification.

Variations in the specific heat before T_β and after T_β were expressed using the numerical formula as follows :

$$Cp = -1E\text{-}15T^6 + 4E\text{-}12T^5 - 5E\text{-}09T^4 + 3E\text{-}06T^3 - 0.0012T^2 + 0.2057T - 13.988 \quad (\alpha+\beta \text{ microstructure}) \tag{1}$$

$$Cp = 2E\text{-}14T^6 - 1E\text{-}10T^5 + 4E\text{-}07T^4 - 0.0005T^3 + 0.4237T^2 - 181.72T + 32390 \quad (\beta \text{ microstructure}) \tag{2}$$

Figure 7 shows the results of the length variation measured according to an increase in temperature up to 1100℃. The length variation, like the specific heat variation, increased in two steps, on the basis of the β transition temperature. It was also found that the coefficient for thermal expansion was 10×10^{-6}/degree. The ductility of Ti-8Ta-3Nb decreased near the β transition temperature as a result of an increase in the volume fraction of the β phase.

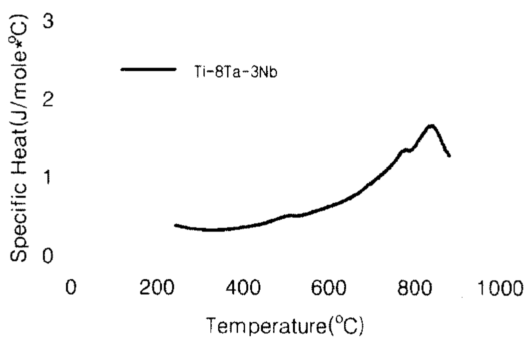

Fig. 5 Specific Heat of Ti-8Ta-3Nb alloys before T_β

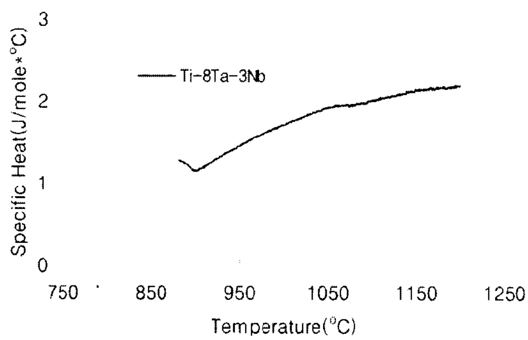

Fig. 6 Specific Heat of Ti-8Ta-3Nb alloys after T_β

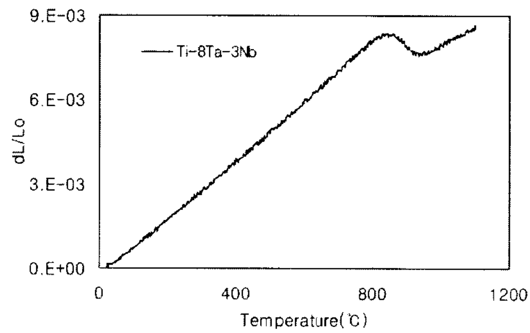

Fig. 7 The variation in the dimension of Ti-8Ta-3Nb alloys according to temperature

4. Conclusion

After the Ti-8Ta-3Nb was manufactured, experiments ascertaining the hardness variation after the solution heat treatment, as well as the variation in specific heat and length according to an increase of temperature, were carried out in as-cast and forged specimens so as to determine the properties as a new biomaterial.

The optimum temperature of the solution heat treatment of Ti-8Ta-3Nb was determined to be 880℃, considering the mechanical properties and the volume fraction of the α phase and their phases shown from the results of the solution heat treatment.

Also, it was found that the β transition temperature of Ti-8Ta-3Nb was between 860℃ and 880℃. Through the hardness experiment and the solution heat treatment it can be inferred that the β transition temperature of Ti-8Ta-3Nb has nothing to do with the as-cast or forged state. The β transition temperature played an important role when designing the hot working schedules for an ingot breakdown in the β field and the subsequent cogging or finish forging in the $\alpha+\beta$ field.

The variation in the lengths and the specific heat measured increased in two steps on the basis of the β transition temperature. It was known that the thermal expansion coefficient is 10×10^{-6}/degree and the microstructural transformation brings the change of the specification. Variations of the specific heat before T_β and after T_β were expressed using the numerical formula.

In recent years, processing maps have been used to design hot working schedules for making near-net shapes in a wide variety of materials. Therefore, it is necessary for specific heat to be a factor in drawing processing maps.

Furthermore, it was found that the β phase volume fraction influences the variations on the specific heat and the length.

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