TENSILE FRACTURE BEHAVIOR AND CASTING DEFECTS OF BETA TYPE Ti-29Nb-13Ta-4.6Zr CAST BY DENTAL PRECISION CASTING PROCESSING

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ABSTRACT

Relationship between tensile properties and casting defect of newly developed beta type titanium alloy, Ti-29Nb-13Ta-4.6Zr, for biomedical applications, and representative $\alpha + \beta$ type titanium, Ti-6Al-4V ELI, for biomedical applications cast by dental precision casting processing using commercial alumina and magnesia based investment materials, and modified magnesia based investment material. Then the effect of specimen diameter on tensile properties of both cast alloys was also investigated.

Elongation of cast tensile specimens of both alloys slightly increases and strength of cast tensile specimen of Ti-6Al-4V ELI increases with decreasing diameters, which is associated with reducing casting defects. Hardness of surface reaction layer decreases, and hardness of matrix decreases by about 50 Hv due to increasing cooling rate by reducing the specimen diameter from 3 mm to 2 mm in both alloys. The microstructures of both cast alloys are a little refined with reducing specimen diameters, but the hardness of surface reaction layers and matrix of both alloys decreases. Therefore, the improvement in tensile properties of the cast specimen of each alloy with a diameter of 2 mm is due to decreasing casting defects.

1 INTRODUCTION

Ti-29Nb-13Ta-4.6Zr, which is a beta type titanium alloy composed of non-toxic and non-allergic elements originally developed for biomedical applications [1] [2] is expected to be applicable not only for dental implants but also for dental products like crowns, inlays, clasps, etc. In order to fabricate dental products, dental precision casting processing is used in general. Casting defects are in general exists in castings fabricated by dental precision casting, and are related to mold materials, that is, investment materials. Commercial alumina and magnesia based investment materials, and modified magnesia based investment material were applied for the dental precision casting of Ti-29Nb-13Ta-4.6Zr in the previous work [3]. The modified magnesia based investment material was judged to be suitable for the precision casting of Ti-29Nb-13Ta-4.6Zr comparing with commercial alumina and magnesia based investment materials because the surface reaction was the weakest and surface appearance was the best.

However, the effect of casting defect on tensile properties of Ti-29Nb-13Ta-4.6Zr cast using modified magnesia based investment material has not been yet clearly understood. The casting defects in Ti-29Nb-13Ta-4.6Zr cast by dental precision casting processing are considered to be different from those of cast conventional alpha-beta type Ti-6Al-4V ELI because the melting point of Ti-29Nb-13Ta-4.6Zr is much higher than that of Ti-6Al-4V ELI. Therefore, tensile fracture behaviors of Ti-29Nb-13Ta-4.6Zr and Ti-6Al-4V ELI cast by dental precision casting processing using commercial alumina and magnesia based investment materials, and modified magnesia based investment material were investigated with relating to casting defects.

2 EXPERIMENTAL PROCEDURES

The materials used in this study were forged bars with a diameter of 30 mm of biomedical beta type Ti-29Nb-13Ta-4.6Zr (Nb: 29.2, Ta: 12.2, Zr: 4.3, Fe: 0.05, C: 0.02, N: 0.04, O: 0.10, bal Ti, mass %, hereafter TNTZ) and alpha-beta type Ti-6Al-4V ELI (Al: 6.17, V: 4.05, Fe: 0.11, O: 0.10, N: 0.04, H: 0.002, bal: Ti, mass %, hereafter Ti64) as comparison. The columnar specimens with a weight of 45 g were cut from each bar after removing the surface oxide layer.

Mold materials (investment materials) used in this study were commercial alumina (hereafter alumina) and magnesia (hereafter magnesia) based investment materials, and modified magnesia based investment material where based material, magnesia, was refined, and silica and alumina were removed. The columnar specimens of each alloy were cast into the molds of tensile specimens with a gauge diameter of 3 mm and a gauge diameter of 2 mm, respectively. Tensile specimens with a diameter of 2 mm were fabricated in order to reduce the casting defects comparing with those with a diameter of 3 mm. Casting was done using a dental casting machine. The surfaces of tensile specimens were sand blasted.

Tensile tests were carried out at a crosshead speed of 8.33×10^{-6} m/s at room temperature using an Instron type machine. Microstructural observations were carried out on the cross sections of the tensile specimens using a light microscope. Vickers hardness measurement was done on the same specimen as used for the microstructural observation from near the surface to the inside of the specimen.

Casting defects including shrinkage and pore were evaluated using on both fracture surface and cross section of gauge part of tensile specimen using a scanning electron microscopy, SEM, and a light microscopy. The casting defects, of which diameters were over 10 μm, were evaluated when they were evaluated on the fracture surface because dimples and casting defects, of which diameters were below 10 μm, were difficult to distinguish each other.

3 RESULTS AND DISCUSSION

3.1 Volume fraction and distribution of size of casting defects

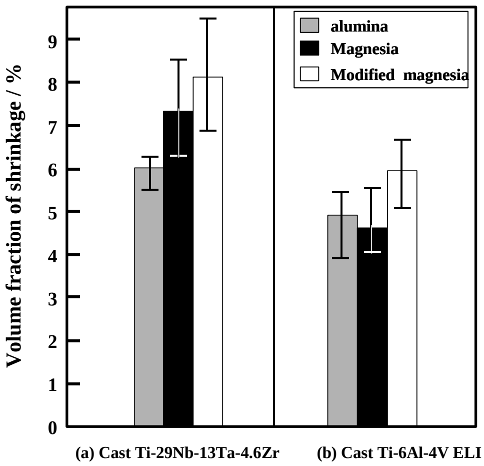

Fig.1 Volume fractions of casting defects measured on fracture surfaces of cast specimens of (a) TNTZ and (b) Ti64 using alumina, magnesia and modified magnesia based investment materials.

The volume fractions of casting defects evaluated on the fracture surfaces of as-cast tensile specimens of TNTZ and Ti64 using alumina, magnesia and modified magnesia based investment materials are shown in Fig.1. In this case, the volume fractions of casting defects are sum of the volume fractions of both shrinkages and pores because the volume fractions of pores are very small (about 0.23 %) in both alloys as will be stated below. The volume fractions of casting defects of TNTZ and Ti64 are the greatest in the modified magnesia based investment material. The volume fraction of casting defect is greater in TNTZ than in Ti64 in every investment material.

The distribution of the number of casting defect as a function of diameter measured on the fracture surface of each cast alloy using modified magnesia based investment material is shown in Fig.2. The number of pore of each cast alloy is very small. The total number of casting defect on the fracture surface of TNTZ is greater than that of Ti64. The maximum diameter of shrinkage in TNTZ is greater than that in Ti64. The former is around 190 μm and the latter is around 130 μm. These trends were nearly the same in each cast alloy using alumina and magnesia based investment materials although the number and the size of shrinkages are a little smaller.

The volume fraction and the number of casting defect measured on the cross section of gauge part of tensile specimen are greater than those measured on the fracture surface, but the number of large casting defects was greater on the fracture surface than on the cross section of gauge part of tensile specimen. Regardless of investment materials and alloys

Therefore, the fracture initiates from relatively large shrinkage, at which the stress concentration becomes to be high, and propagates with linking them. As stated above, the casting defects are mainly shrinkages. The volume fraction and the size of pore are very small. The effect of pore on the tensile properties of each cast alloy is considered to be negligibly small.

Figure 3 shows relationships between the tensile strength or elongation and the volume fraction of casting defect (shrinkage) measured on the cross section of the gauge part of cast tensile specimen of TNTZ and Ti64 using modified magnesia based investment material. Elongation of both alloys slightly decreases with increasing the volume fraction of shrinkage. Tensile strength of TNTZ decreases a little according to the increase in volume fraction of shrinkage while that of Ti64 decreases clearly with increasing volume fraction of shrinkage. Since the surface reaction layer formed on the specimen increases the strength and decreases the ductility of both cast alloys [3], the degradation in elongation and strength of both cast alloy with increasing the volume fraction of shrinkage reflects the effect of the volume faction of shrinkage.

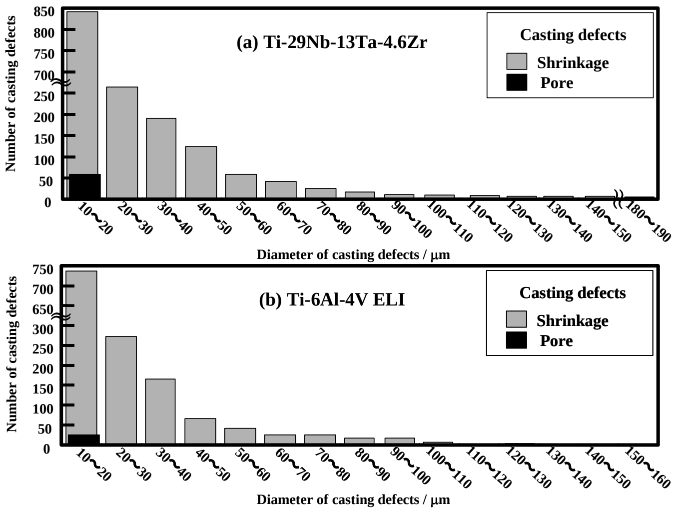

Fig.2 Distributions of casting defects evaluated on fracture surfaces of cast specimens of (a) TNTZ and (b) Ti64 using modified magnesia based investment material.

3.2 Effect of specimen diameter on casting defects

The volume fractions of casting defects including both shrinkage and pore in cast specimens of TNTZ and Ti64 with diameters of 2 and 3 mm using magnesia and modified magnesia based investment materials are shown in Fig.4. The distribution of the number of casting defects as a function of diameter measured on the fracture surface of cast specimen of each alloy using modified magnesia based investment material is shown in Fig.5. The volume fraction of casting defect of the cast specimen with a diameter of 2 mm decreases by 1/3 of that of the cast specimen with a diameter of 3 mm in each cast alloy. The number and diameter of shrinkage remarkably decrease in the cast specimen with a diameter of 2 mm comparing the case of the cast specimen with a diameter of 3 mm. This trend is similar in the case of magnesia based investment materials.

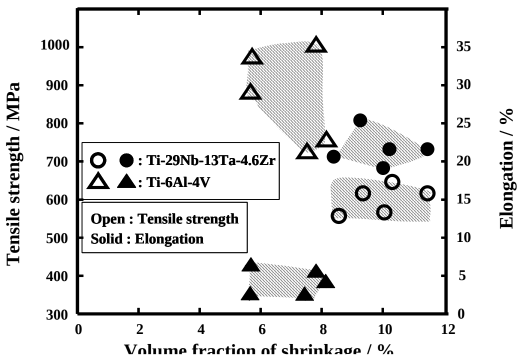

Fig.3 Relationships between tensile strength or elongation and volume fraction of shrinkages measured on cross sections of cast tensile specimens of TNTZ and Ti64 using modified magnesia based investment material.

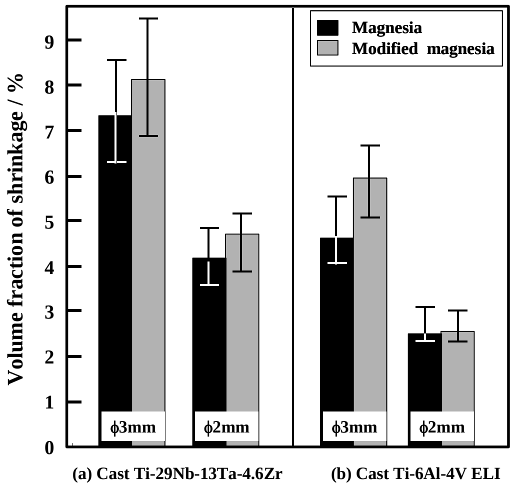

Fig.4 Volume fractions of casting defects measured on fracture surfaces of cast specimens of (a) TNTZ and (b) Ti64 with diameters of 2 and 3 mm using magnesia and modified magnesia based investment materials.

3.3 Effect of specimen diameter on tensile properties

Tensile strength, 0.2 % proof stress and elongation of the cast specimens of TNTZ and Ti64 with diameters of 2 and 3 mm using magnesia and modified magnesia based investment materials are shown in Figs.6 ad 7. The tensile strength and 0.2 % proof stress of cast specimens of TNTZ with diameters of 2 and 3 mm using magnesia based investment material are nearly the same while elongation is a little greater in the specimen with a diameter of 2 mm than in the specimen with a diameter of 3 mm. The nearly the same trend is obtained in the case of modified magnesia based investment material, but the elongation of the specimen with a diameter of 2 mm is clearly greater than that of the specimen with a diameter of 3 mm.

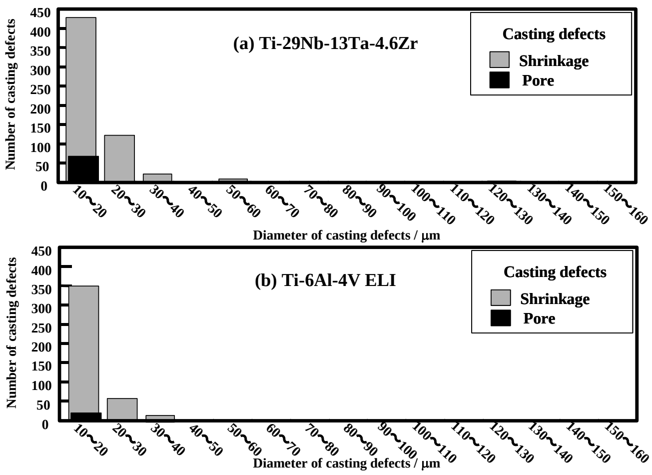

Fig.5 Distributions of casting defects evaluated on fracture surfaces of cast specimens of (a) TNTZ and (b) Ti64 with a diameter of 2 mm using magnesia based investment material.

Tensile strength, 0.2 % proof stress and elongation of the cast specimens of Ti64 with diameters of 2 and 3 mm using magnesia based investment material are nearly the same. Tensile strength and 0.2 % proof stress of the cast specimen of Ti64 with a diameter of 2 mm using modified magnesia based investment material is greater than that of the cast specimen with a diameter of 3 mm. Elongation of the cast specimen of Ti64 with a diameter of 2 mm using modified magnesia based investment material is a little greater than that of the cast specimen with a diameter of 3 mm.

3.4 Effect of specimen diameter on microstructure and hardness of specimen using modified magnesia investment material

The microstructure of the cast specimen with a diameter of 2 mm was a little smaller than that of the cast

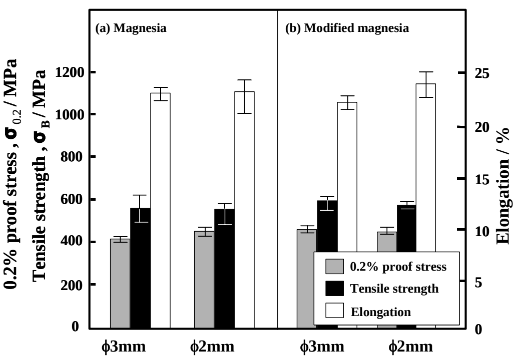

Fig.6 Tensile properties of cast specimens of TNTZ with diameters of 2 mm and 3 mm using (a) magnesia and (b) modified magnesia based investment materials.

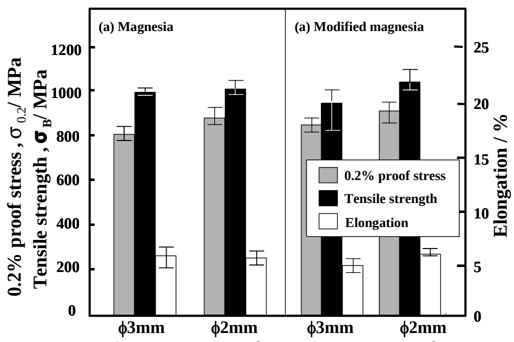

Fig.7 Tensile properties of cast specimens of Ti64 with diameters of 3mm and 2mm using (a) magnesia and (b) modified magnesia based investment materials.

specimen with a diameter of 3mm, which would lead to increase the strength regardless of alloys. On the other hand, from the results of the hardness measurement of the specimen matrix and surface reaction layer, the hardness of the specimen matrix and surface reaction layer was smaller in the cast specimen of each alloy with a diameter of 2 mm than in the cast specimen of each alloy with a diameter of 3mm. Therefore, the improvement in tensile properties of the cast specimen of each alloy with a diameter of 2 mm is due to decreasing casting defects.

CONCLUSIONS

(1) Elongation of cast tensile specimens of Ti-29Nb-13Ta-4.6Z and Ti-6Al-4V ELI slightly increases and strength of cast tensile specimen of Ti-6Al-4V ELI increases with decreasing diameters, which is associated with reducing casting defects.

(2) Hardness of surface reaction layer decreases, and hardness of matrix decreases by about 50 Hv due to increasing cooling rate by reducing the specimen diameter from 3 mm to 2 mm in both alloys.

(3) The microstructures of both cast alloys decreases with reducing specimen diameters, but the hardness of surface reaction layers and matrix of both alloy

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