연구논문

# 진공 원심 주조를 이용한 Ti-48Al-2Cr-2Nb 합금 터보차저 터빈휠 제작

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# Manufacturing of Ti-48Al-2Cr-2Nb Alloy Turbocharger Turbine Wheel by Vacuum Centrifugal Casting

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초 록

고온 환경에 대한 우수한 특성을 바탕으로 산업 장비의 고온 재료에 Ti-48Al-2Cr-2Nb 합금이 사용된다. 본 연구에서는 Ti-48Al-2Cr-2Nb 합금 터보 차저 터빈 휠을 진공 원심 주조 방법으로 제작했다. 알루미나 몰드를 이용한 원심 주조시 터보 차저 터빈 휠 블레이드의 미스런 불량을 방지하기 위한 조건을 조사하였다. 진공 원심 주조로 제조된 합금의 미세 구조는 광학 현미경 (OM), 마이크로 비커스 경도 분석기 (HV), X- 선 회절 (XRD) 및 SEM-EDS로 연구하였다. 주조된 Ti-48Al-2Cr-2Nb 합금의 경도 및 SEM-EDS 결과는 산화층 (α- 케이스)의 두께가 일반적으로 50µm 미만임을 보여주었다. 예열 온도 1,100oC, RPM 260, 게이트 크기가 큰 알루미나 몰드의 경우 미스런 불량이 거의 없었다. 따라서 높은 예열 온도, 중간 RPM, 큰 게이트 크기 및 알파 케이스 형성 억제를 위한 알루미나 몰드를 통해 미스런이 적은 Ti-48Al-2Cr-2Nb 합금 터보 차저 터빈 휠을 얻을 수 있음을 확인했다.

**핵심용어;** 진공원심주조, Ti-48Al-2Cr-2Nb 합금, 산화층, 터보 차저 터빈 휠, 알루미나 몰드.

Abstract

Based on its good compatibility with high-temperature environments, the Ti-48Al-2Cr-2Nb alloy is used for high-temperature materials of industrial equipment. In this study, a Ti-48Al-2Cr-2Nb alloy turbocharger turbine wheel was fabricated by a vacuum centrifugal casting method. The conditions that prevent misrun defects of the turbocharger turbine wheel blade from centrifugal casting using alumina molds were investigated. The microstructure of the alloy prepared by vacuum centrifugal casting was studied by means of optical microscopy (OM), with a micro-Vickers hardness analyzer (HV), by X-ray diffraction (XRD) and by SEM-EDS. The HV and SEM-EDS examinations of the as-cast Ti-48Al-2Cr-2Nb alloy showed that the thickness of the oxide layer (α-case) was typically less than 50 µm. At a high preheating temperature of 1,100°C, a moderate RPM of 260, and with an alumina mold with a large gate size, there were almost no misrun defects. Therefore, it was confirmed that a Ti-48Al-2Cr-2Nb alloy turbocharger turbine wheel with fewer misrun defects could be achieved through a high preheating temperature, a moderate RPM, a large gate size and an alumina mold to suppress the formation of alpha-case components.

**Key words;** Vacuum centrifugal casting, Ti-48Al-2Cr-2Nb, Oxide layer, Turbine wheel and Alumina mold.

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Received: Sep. 23, 2020 ; Revised: .Oct. 30, 2020 ; Accepted: Jan. 21, 2021
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Journal of Korea Foundry Society
2021. Vol. 41 No. 2, pp. 127~131
http://dx.doi.org/10.7777/jkfs.2020.41.2.127
pISSN 1598-706X / eISSN 2288-8381

## 1. Introduction

Ti alloys have good mechanical properties in commercial fields, and the application is still increasing [1,2]. Ti-6Al-4V has an excellent property and is an α+β type alloy. It combines the characteristics of α type Ti alloy and β type Ti alloy. In addition, it is an alloy with high utility because it can obtain various microstructures and high mechanical properties [3-5]. γ-TiAl alloy has only half the specific gravity of nickel based alloys and is developed as a representative heat resistant alloy, maintains an intermetallic compound structure up to 1700K, close to its melting point, and has high specific strength, excellent oxidation resistance, and high-temperature creep characteristics. So, now on the basis of these excellent properties, applying for an aircraft engine blade is conducted as research topics [6-8]. In particular, TiAl alloy is oxidized at 1100K and shows the level of embrittlement, such as ceramic under fracture and hot dynamic loads, so it is being used in the suction side of the pressure at low engine front end and blades [9,10]. Layered structure, such as a microstructure having TiAl/$Ti_3Al$, is put into practical use. Fully lamellar structure of TiAl/$Ti_3Al$ has low ductility, so studies for improvement have been attempted with the introduction of unidirectional solidification method. Thus, a study for controlling the layered boundary for the softening is conducted. And, the global automotive market is competitive, so new technologies and security are the high interest for the application. In the case of a gasoline turbochargers, excellent effects in improving fuel efficiency and emissions reduction are showed. However, TiAl based alloys has the low flow ability of the molten alloy, so the molding process for improving a precise shape is very difficult. Thus, the rim of the wheel needs a high speed centrifugal force in the casting process. In the case of Ti-48Al-2Cr-2Nb castings, the temperature of the molten metal or preheating of the mold can improve a centrifugal force of a molten metal to secure the fluidity more effective [11-14]. In this study, high speed centrifugal casting conditions were tested to manufacture Ti-48Al-2Cr-2Nb alloy turbine wheels for turbochargers without misrun defects.

## 2. Experimental Procedure

Table 1 shows the centrifugal casting conditions carried out in this study and the composition analysis with EDX for the Ti-48Al-2Cr-2Nb alloy (No. 4 specimen) is shown in Table 2. The casting process was conducted at three kinds of preheating temperatures 650°C, 1000°C and 1100°C. Zirconia and alumina molds were used to find optimum centrifugal casting process having less misrun defects. Vacuum atmosphere ($5.0\times10^{-2}$ Torr) was reached in 0.5 sec after rotation speed of 260 rpm. In addition, the phase analysis of the centrifugally casted Ti-48Al-2Cr-2Nb wheel product was performed using an optical microscope (Optical Microscopy), XRD (X-ray Diffraction), SEM-EDS (Scanning Electron Microscopy - Energy Dispersive X-ray Spectroscopy), and Micro Vickers hardness tester.

Table 1. Composition of Ti-48Al-2Cr-2Nb alloy prepared by vacuum centrifugal casting

| | Atomic % |
|---|---|
| Ti | 44.31 |
| Al | 45.85 |
| Nb | 2.03 |
| Cr | 1.60 |
| Ni | 0.02 |
| Si | 0.03 |
| O | 6.16 |

Table 2. Conditions of vacuum centrifugal casting tests

| Specimen No. | Preheating temperature (°C) | RPM | Gate size (mm) | Mold |
|---|---|---|---|---|
| 1 | 650 | 280 | 25 | Zirconia |
| 2 | 1000 | 280 | 25 | Zirconia |
| 3 | 1000 | 250 | 25 | Alumina |
| 4 | 1100 | 260 | 30 | Alumina |

## 3. Results and Discussion

The horizontal vacuum centrifugal casting machine of 10kg capacity used in this study is shown in Fig. 1 and Table 2 shows the composition analysis of the Ti-48Al-2Cr-2Nb alloy turbocharger product cast by centrifugal casting. As can be seen in Table 2, the ratio of the Ti-48Al-2Cr-2Nb alloy composition of the specimen prepared by the centrifugal casting method confirming that the final desired Ti-48Al-2Cr-2Nb (Al 48 atomic %) composition was successfully prepared. In addition to Ti and Al, which are

Fig. 1. Vacuum centrifugal casting apparatus for Ti-48Al-2Cr-2Nb alloy.

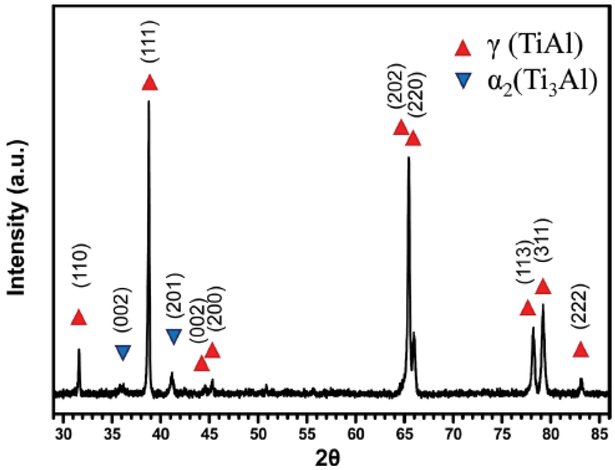
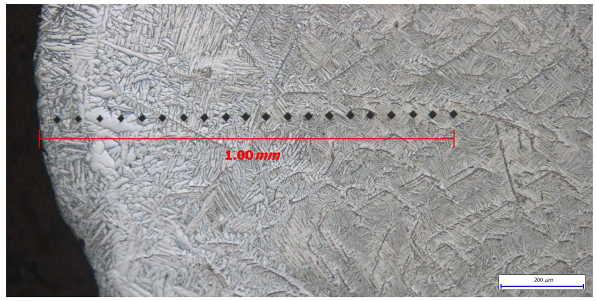
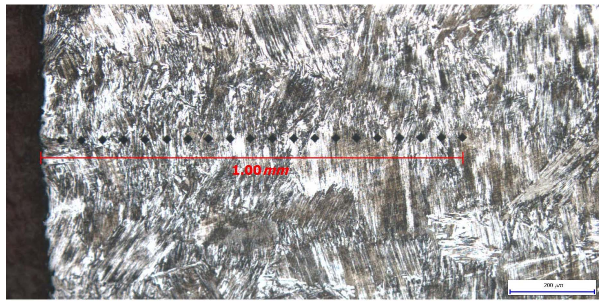



Fig. 2. XRD result of the Ti-48Al-2Cr-Nb alloy (No.4 specimen) prepared by centrifugal casting.



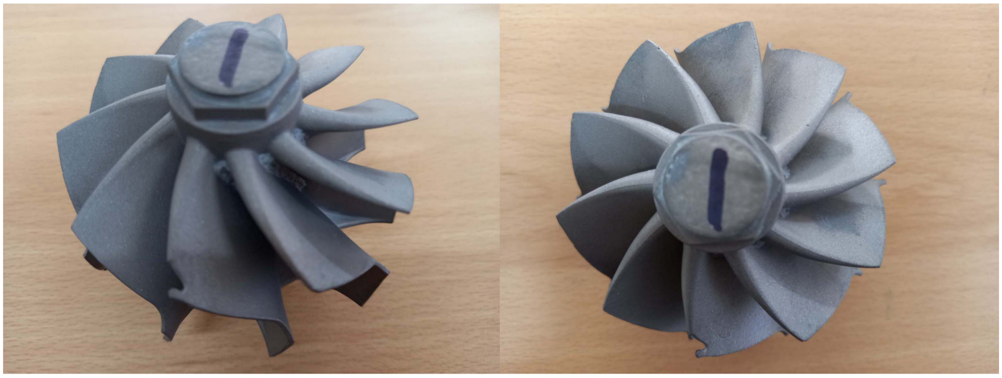

(a) No. 1 specimen



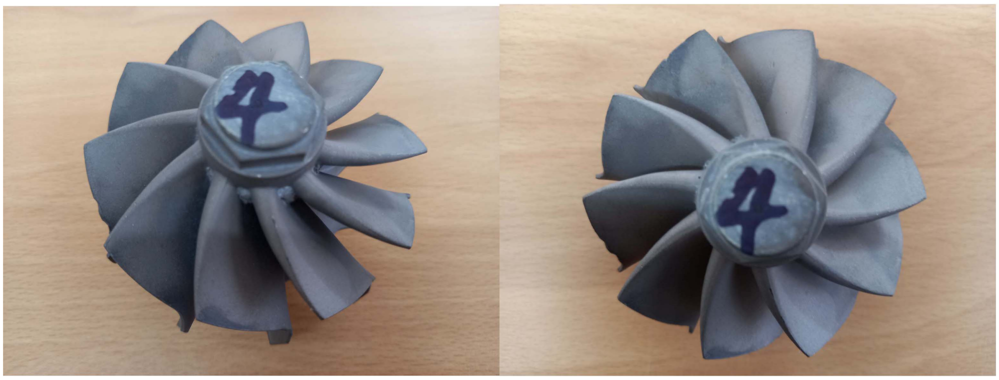

(b) No. 4 specimen

Fig. 3. Microstructures of Ti-48Al-2Cr-2Nb alloy turbocharger turbine wheels by centrifugal casting with (a) zirconia mold and (b) alumina mold.

the main compositions, a small amount of Nb, Cr, Ni, and Si were contained, and the content of oxygen was observed to be high. This oxygen content was attributed to the oxygen contained in the alpha-case on the surface of the cast specimen. Fig. 2 is an XRD analysis result of Ti-48Al-2Cr-2Nb alloy prepared by the centrifugal casting method. As can be seen in Fig. 2, the Ti-48Al-2Cr-2Nb alloy consists of a γ-TiAl phase, which is a tetragonal lattice (a=0.4016nm, c=0.4073nm, c/a ratio 1.014), as the main phase. The two kinds of molds used in the experiments are zirconia and alumina, and the casting structures from these molds can be seen in Fig. 3. In the Ti-Al binary system, two different-type microstructure such as dendritic state was confirmed. In this alloy system, it was known that the shape of the dendritic phase changed when the β-phase (bcc) is formed as a primary crystal and when the α-phase (hcp) was formed as a primary crystal [15,16]. In this experiments, dendritic structure was found with both two kinds of molds as can be seen in Fig. 3. In Fig. 4, we can see that in order to obtain less misrun defect casting, a high preheating temperature and alumina mold for alpha-case formation was needed. In addition, moderate RPM 260 with large gate size was applied for better fluidity. At low preheating temperature 600°C with high RPM 280 using zirconia mold, the turbo charger turbine wheel showed a problem of misrun defects on the turbocharger turbine wheel blade. In the case of high preheating temperature 1100°C, moderate RPM 260, and alumina mold with large gate size, there were almost no misrun defects. This result was analyzed that in the case of the alumina mold, the alpha-case component was formed inside the mold with preheating, and the generation of alpha-case on the surface of the cast product was suppressed as much as possible when in contact with the molten metal. Alpha-case is a kind of oxidation layer which increase the surface hardness and make a problem on machining when the hardened thickness is over 50μm. In this experiments, surface hardness could be seen in Fig. 5 with using a micro Vickers (Micro Vickers) hardness tester and it showed a hardness value



(a) No. 1 specimen



(b) No. 4 specimen

Fig. 4. Improvement of Ti-48Al-2Cr-2Nb alloy misrun defects (a) No. 1 specimen with misrun defectcs on the blade (b) No. 4 specimen without misrun defects on the blade.

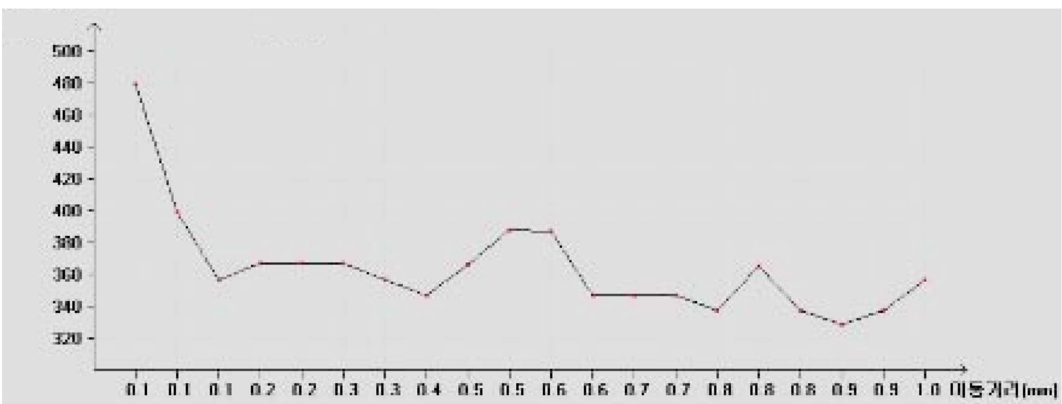



Fig. 5. Hardness profile of the Ti-48Al-2Cr-2Nb alloy (No. 4 specimen) as depth from the surface.

measured in accordance with 50μm intervals from the surface of the specimen The second point 50μm from the surface showed hardness value as 400 compared to the first point, surface hardness value 480. In general, Ti and TiAl molten metal were active in the casting due to the reaction layer. However, the hardness is observed after the process, the alpha-case was found as a low level. In particular, it was known that alumina molds generally form an alpha-case of 500~600μm or more [15-19]. However, in this study, an alumina mold was used to suppress the generation of alpha-cases generated on the surface of the cast when contacting the molten metal through process variables as much as possible. In Fig. 5, from the graph of the change in hardness value, it was confirmed that the alpha-case layer was formed in the region of less than 50 μm from the surface, and the formation of this alpha-case layer was found to approve the satisfactory casting result. Also, in Fig. 6, SEM-EDS showed the surface layer analysis result. Here again, the thickness of the oxide layer is less than 50 μm, which is consistent with the hardness value analysis.

## 4. Conclusions

In this study, Ti-48Al-2Cr-2Nb alloy turbocharger turbine wheel was cast using a high-speed vacuum centrifugal casting method to manufacture a turbine wheel for a turbocharger. Alumina molds were used to produce Ti-48Al-2Cr-3Nb turbocharger turbine wheel products with no misrun defects. As a result of XRD analysis of Ti-48Al-2Cr-2Nb alloy, it was confirmed that it was composed of γ-TiAl phase. As a result of observation by SEM, it was confirmed that dendritic structure was formed with both two kinds of molds and in the Micro Vickers hardness value change graph, it was confirmed that the alpha-case layer was formed in the hardness elevation area in the area less than 50 μm from the surface. And, it was noticed again that the results of SEM-EDS analysis were similar to that grape of the change in the hardness value. In the case of high preheating temperature 1100$^{o}$C, moderate RPM 260, and alumina mold with large gate size, there were almost no misrun defects were found. This result was analyzed that in the case of the alumina mold, the alpha-case component was formed inside the mold with preheating. Therefore, it was confirmed that a misrun free Ti-48Al-2Cr-2Nb alloy turbocharger turbine wheel could be achieved through a high preheating temperature, moderate RPM, appropriate mold selection with large gate size.

## Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (No. 2020R1F1A1050885).

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