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Variation in lattice parameters and strain of sintered titanium powder by advanced hydrogen sintering process

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ABSTRACT

The effects of hydrogen injection during a sintering process on lattice parameters and the strain of titanium powder have been investigated using X-ray diffractometry (XRD). In previous works, the sintering properties of titanium were improved by hydrogen injection. The present work shows that the hydrogen injection directly impacts the lattice parameters and the strain of titanium. The result shows that the hydrogen injection reduced the lattice parameters with the d-space, *a*, *c*, and *c*/*a*, and the cell volume compared with the reference samples obtained under an argon atmosphere. This lattice structure variation from the hydrogen injection is mainly due to the suppression of oxidation during sintering at high temperatures and the reduction of the interstitial elements such as oxygen.

1. Introduction

In recent years, due to the increased use of non-ferrous metals in modern hi-tech industries, the corresponding demand is increasing rapidly. Among the non-ferrous metals, titanium is one of the most important due to its good properties such as low specific gravity and high strength. In addition, titanium has been used in many industries due to its excellent corrosion resistance and biocompatibility [1–3]. However, titanium is sometimes difficult to use because of its high melting temperature and requirement for powder-metallurgy (PM) processing rather than casting [4–6]. The powder sintering of an active metal such as titanium is generally conducted under a vacuum or in an inert gas atmosphere such as argon [5,7]. However, in an inert gas atmosphere, as opposed to a vacuum, oxidation of the powder surface is inevitable, and degradation of the sintering property occurs. As a potential solution to the oxidation and gas-contamination problems, the injection of hydrogen gas into the inert gas atmosphere in the sintering process has been proposed [8–10]. The hydrogen injection process resulted in improved properties of the titanium sintered body that were obtained by the sintering and limiting of the oxidation and gas contaminations, while hydrogenation was simultaneously prevented.

An issue arises whereby the sintered density increased to more than 1200 °C because the hydrogen injection promotes sintering by suppressing the oxidation and the gas contamination of the titanium powder surface at high temperatures [8]. Wang and Lee groups reported that the roles of the hydrogen on the oxidation of titanium during the sintering [11,12]. These changed properties consequently varied the lattice parameters of the sintered titanium, because the contamination of the interstitial elements such as oxygen was suppressed by the hydrogen injection. Theoretically, the lattice parameters of titanium and titanium alloys depend on the interstitial elements in solid solutions [1,2,13]. In particular, the solubility values of oxygen and nitrogen in titanium are high and increase with temperature [14]. In a previous work, the experimental group of the present study developed a new titanium-sintering process, wherein the superior sintering properties were investigated. Therefore, in this study, the changes of the lattice structure that were caused by the hydrogen injection during the sintering of the titanium powder under an argon atmosphere were investigated.

2. Materials and methods

In the experimental procedure, a 99.9% 3 N-grade titanium powder (High Purity Chemicals, Japan) was used as a raw material. The average particle size of the titanium powder is 45 μm. The weight of the titanium powders for the sintering is 5 g. The titanium powders were compacted under a 25-Mpa pressure using a vertical single-axis press. The compacted specimens were placed at the center of the sintering furnace. The argon (2000 cm^3/min) or argon (1000 cm^3/min) + hydrogen (1000 cm^3/min) mixed-gas combination was injected from one end of the sintering furnace using a mass-flow controller. The heating rate of the furnace was 10 °C/min, and the compacted specimens were held at 1000, 1100, 1200, 1300, and 1400 °C for 3 h at each temperature. The specimens were then extracted from the furnace and cooled to

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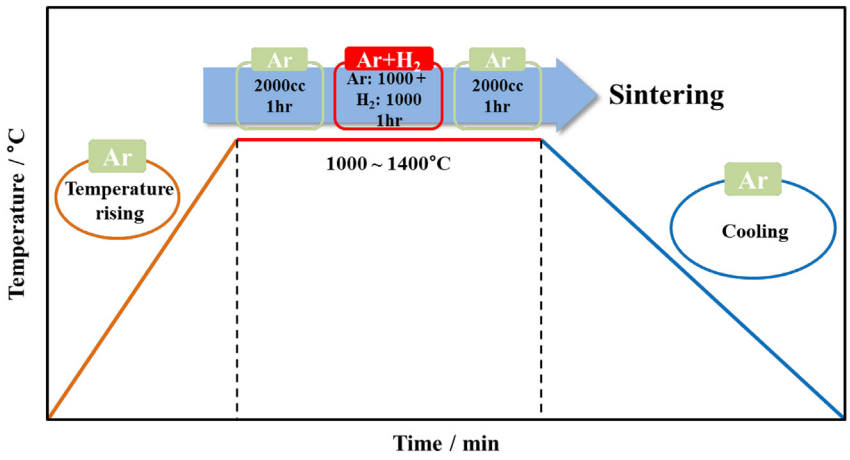

Fig. 1. Diagram of sintering process of this experiment.

room temperature. The detailed atmospheric conditions are shown in Fig. 1. The crystal structures of the titanium-sintered bodies were determined using the MAX-2500 X-ray diffraction (XRD) apparatus (Rigaku, Japan).

3. Results and discussion

The lattice structures of the sintered bodies that were obtained using the previously mentioned process were analyzed using XRD. During the sintering process, hydrogen was injected into the core time, and a sound sintered body was obtained using this process. Fig. 1 shows the schematic diagram of the sintering process used in this study. The sintering process under the argon atmosphere is represented as ASP, while the sintering process with the hydrogen injection is represented as HSP.

Fig. 2 shows the XRD results of the sintered titanium bodies that were obtained using ASP and HSP. All of the sintered bodies were

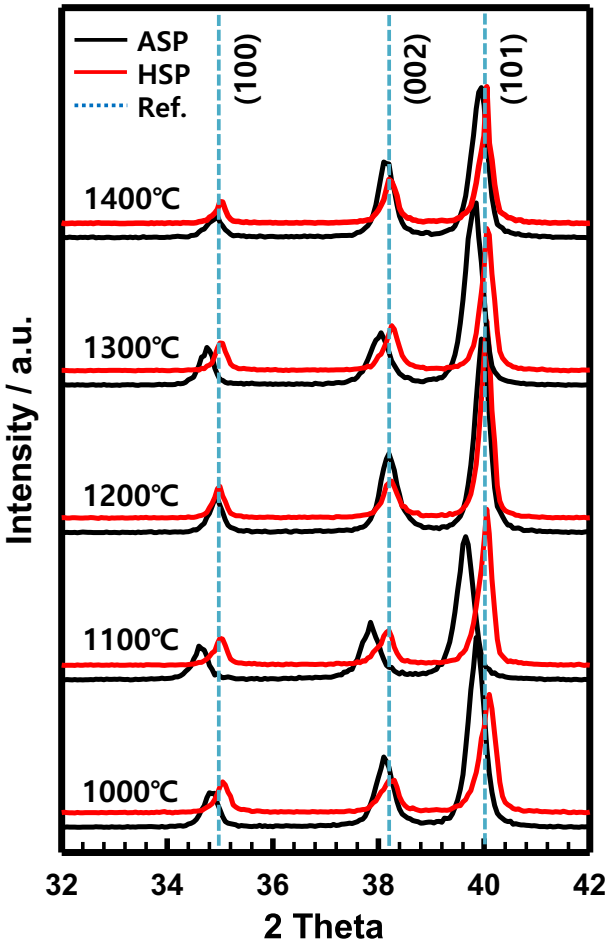

Fig. 2. XRD results of the titanium sintered bodies obtained by the ASP and HSP at the sintering temperature range of from 1000 °C to 1400 °C.

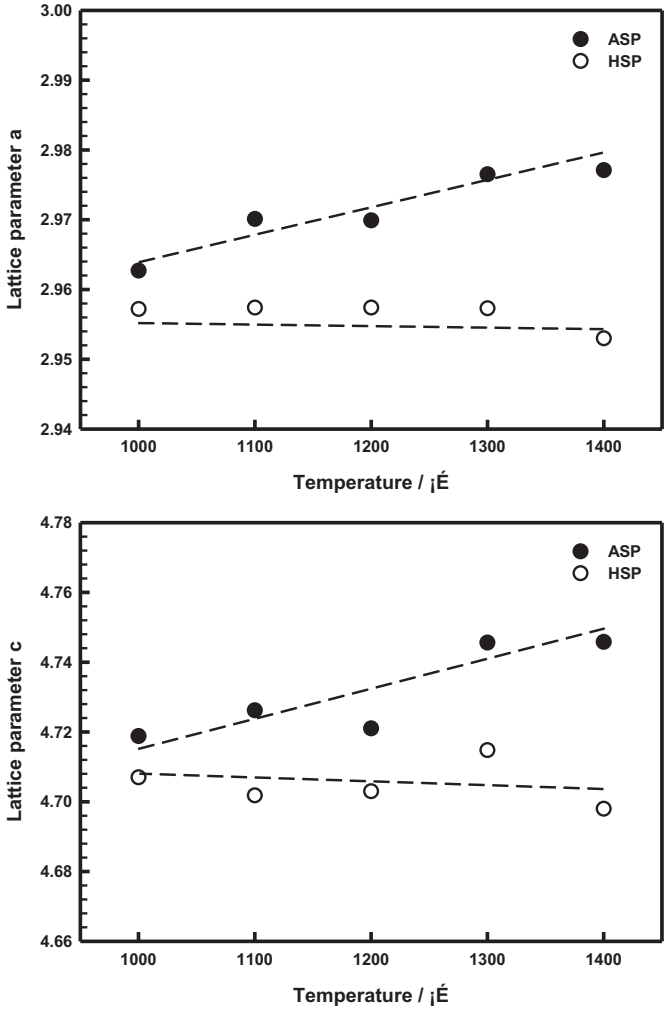

Fig. 3. Variations of the lattice parameters (*a* and *c*) of the titanium sintered bodies obtained by the ASP and HSP as a function of sintering temperature.