Achieving near-isotropic high tensile performance in additively manufactured Ti through interstitial solute influences

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Abstract

In our pursuit of innovative AM materials, we have developed a rare metal-free titanium alloy recognized for its remarkable specific strength, high ductility, and biocompatibility, while emphasizing cost-efficiency. Key challenges like the costly Ti powder containing rare metals such as vanadium and mechanical property dependence on layering direction drove us to develop a Ti-(N) powder with a Core-Shell structure, incorporating cost-effective nitrogen for solid solution strengthening. This material, used in titanium additive manufacturing, attains outstanding strength and ductility through crystal structure refinement and orientation control via nitrogen solid solution atoms, ensuring isotropic mechanical properties. These findings unveil exciting possibilities for diverse industry applications, establishing this alloy as a rare metal-free, mechanically superior alternative to conventional Ti-6Al-4V alloys.

Background & Results

The widely used Ti-6Al-4V alloy, prominent in aircraft and biomaterial applications, is primarily reliant on rare metals. However, concerns regarding the supply of rare metals and the potential for price volatility due to international circumstances have prompted the need for novel titanium alloy designs that are independent of rare elements. In response, novel titanium alloy designs based on elemental strategies have emerged, advocating the use of abundant and cost-effective elements like oxygen, nitrogen, carbon, and iron. Notably, these elements, typically deemed impurities affecting titanium's ductility, have predefined limits under JIS/ASTM standards. In the context of metal AM, a unique challenge arises in which crystal grains tend to elongate during rapid solidification, causing pronounced mechanical anisotropy. To address these challenges, our research pioneers a cost-effective, rare metal-free titanium alloy emphasizing mechanical functionality. By using structured Ti-(N) powder, we have successfully developed a novel titanium material, boasting remarkable strength and ductility, utilizing the solid solution characteristics of nitrogen components. Notably, in the ultra-fast solidification process of AM, nitrogen not only impedes the growth of α-Ti grains but also fosters the nucleation of a metastable martensitic phase with random crystal orientation. This results in the formation of fine crystal grains and reduces mechanical anisotropy. As a result, we have achieved a rare metal-free titanium alloy, while outperforming the conventional Ti-6Al-4V alloy through the sole addition of nitrogen. This achievement opens new horizons for advanced applications across various industries.

Significance of the research and Future perspective

An economical titanium additive manufacturing material, enhanced with nitrogen, has achieved impressive strength, ductility, and isotropic, making it a compelling alternative to costly Ti-6Al-4V alloy. This development offers economic advantages and shows promise across diverse industries. Especially in resource-limited Japan, this advancement positions us as a leader in the titanium materials industry. This strategic transition reduces dependence on rare metals, mitigating geopolitical risks, and fosters technologies for regenerating and recycling raw materials, aligning with the circular economy. We are committed to actively promoting initiatives related to this noble undertaking.

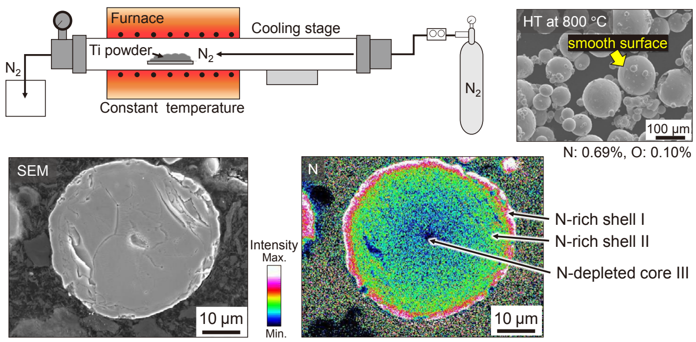

Figure 1. The modification of Ti powder via gas-solid interactions process at an elevated temperature presents a method that affords two noteworthy advantages. Firstly, it maintains the exceptional flowability of the feedstock. Secondly, it ensures the potential for the even distribution of N following the fabrication process.

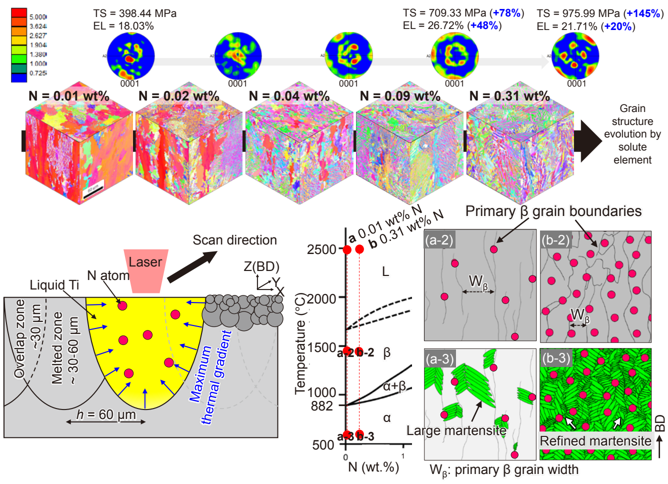

Figure 2. The transformation of grain structure resulting from an increase in N concentration, elucidating through the utilization of 3D IPF mappings for α-Ti, complemented by schematic representations that depict the microstructural changes occurring during the rapid solidification process.

Patent

Treatise
Issariyapat, Ammarueda; Umeda, Junko; Kondoh, Katsuyoshi et al. Development of core–shell-structured Ti-(N) powders for additive manufacturing and comparison of tensile properties of the additively manufactured and spark-plasma-sintered Ti-N alloys. Advanced Powder Technology, 2021, 32, 2379-2389. doi: 10.1016/j.apt.2021.05.023
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Keyword titanium (Ti), nitrogen (N), tensile properties, additive manufacturing (AM)