

## EFFECTS OF SiC ADDITION ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF TITANIUM ALUMINIDE ALLOY PRODUCED BY SELECTIVE LASER MELTING

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<https://doi.org/10.37904/metal.2021.4240>

### Abstract

Ti<sub>2</sub>AlNb-based titanium matrix composites reinforced by silicon carbide particles/fibers have received great attention for light-weight aero-space applications at high service temperatures since titanium orthorhombic alloys demonstrate an attractive combination of mechanical properties, low density, and are suitable for matrix materials. Additive Manufacturing is a promising way of producing SiC/Ti<sub>2</sub>AlNb composites because it offers a possibility to produce parts with a high degree of design-freedom and good mechanical properties. In this work, Ti<sub>2</sub>AlNb-based alloy powder was blended with SiC whiskers and used in Selective Laser Melting process to produce bulk samples. Microstructure, phase composition, and microhardness of the obtained alloys were investigated with regards to SiC whiskers volume fraction.

**Keywords:** Selective laser melting, additive manufacturing, Ti-22Al-25Nb, silicon carbide

### 1. INTRODUCTION

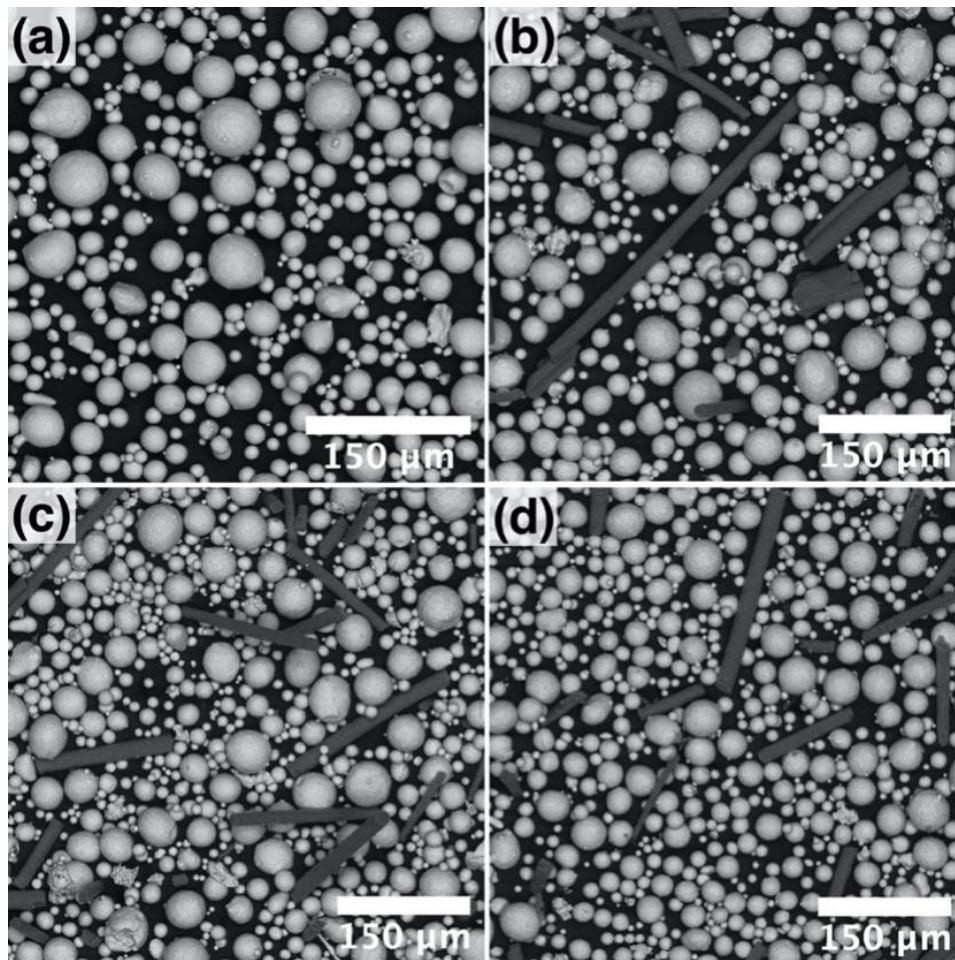
Ti<sub>2</sub>AlNb-based titanium matrix composites reinforced by silicon carbide particles/fibers have received great attention for light-weight aero-space applications at high service temperatures since titanium orthorhombic alloys demonstrate an attractive combination of mechanical properties, low density, and are suitable for matrix materials [1,2]. At the same time, traditional methods of manufacturing of titanium aluminide alloys are very labor- and time-consuming due to a complex chemical composition of such alloys, their brittleness at room temperature, and hard machinability [3,4].

Additive Manufacturing (AM) is a promising way of producing SiC/Ti<sub>2</sub>AlNb composites because it offers a possibility to produce parts with a high degree of design-freedom and good mechanical properties [5]. However, high cooling rates associated with AM require utilizing powder-bed preheating during the manufacturing process to avoid cracking of the material [6,7]. SiC-reinforced Ti<sub>2</sub>AlNb-based alloys have been produced using foil-fiber-foil method [8] and hot isostatic pressing [1,9] which showed promising results. The possibility of using AM techniques to obtain SiC/Ti<sub>2</sub>AlNb composites has not been investigated yet.

In this work, Ti<sub>2</sub>AlNb-based alloy powder was blended with SiC whiskers and used in Selective Laser Melting process to produce bulk samples. Microstructure, phase composition, and microhardness of the obtained alloys were investigated with regards to SiC whiskers volume fraction.

### 2. MATERIALS AND METHODS

Gas atomized powder (**Figure 1, a**) of Ti-24Al-25Nb-1Zr-1.4V-0.6Mo-0.3Si (at%) alloy produced by electrode induction gas atomization (EIGA) and supplied by AMC Powders (China) was used in the SLM process. The particle size of the powder ranged from 14 to 52 μm with a mean particle size  $d_{50}$  = 29 μm. The initial powder consists of B2/β-solid solution obtained due to rapid crystallization during the atomization process [10]. Si-TUFF™ silicon carbide whiskers with a mean diameter of 7 μm and length 100–500 μm were blended with the titanium alloy powder using a tumbler mixer and 12 h mixing time.



**Figure 1** SEM images of (a) the initial Ti<sub>2</sub>AlNb-based alloy powder and the powder blended with (b) 5 vol.%, (c) 10 vol.%, and 15 vol.% SiC whiskers

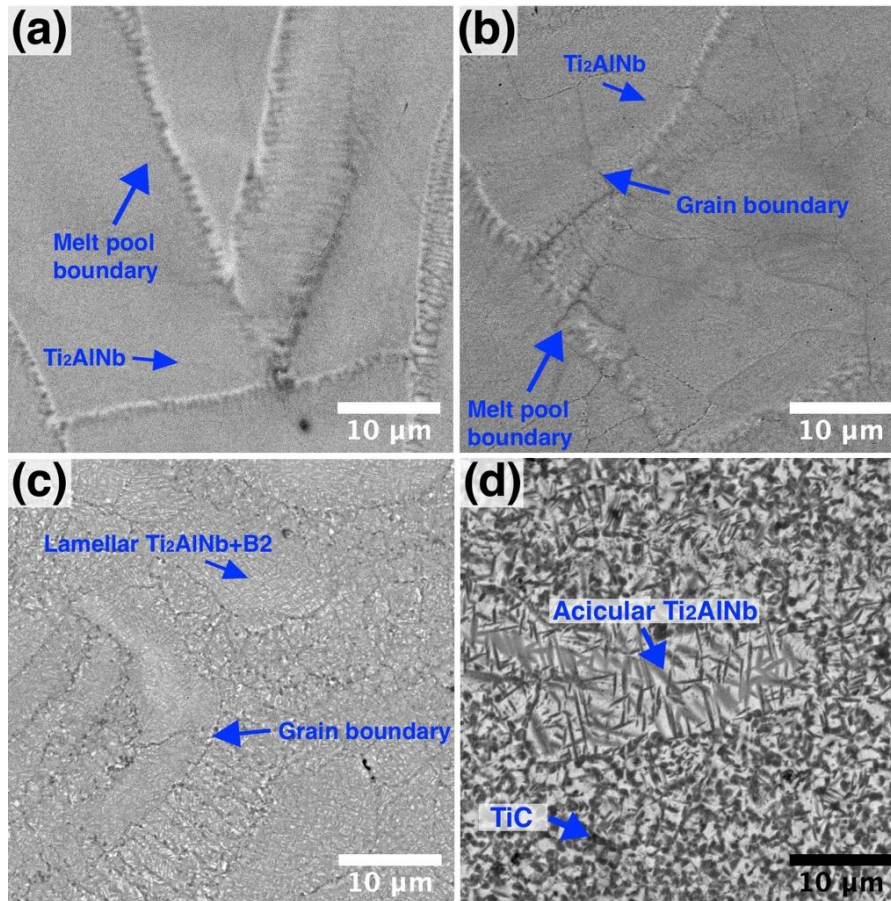
The samples were manufactured by the SLM process using AconityMIDI (Aconity3D GmbH, Germany) system equipped with a 1070 nm wavelength fiber laser with a maximum power of 1000 W. Cylindrical samples with 10 mm diameter and 20 mm height were fabricated for the investigation. The samples were fabricated on a Ti-6Al-4V substrate, which was put on a molybdenum platform. The molybdenum substrate was inductively preheated to a set temperature, which was continuously controlled by a thermocouple under the molybdenum platform. The titanium substrate was then conductively heated by the molybdenum substrate before starting the L-PBF process. The process chamber was continuously flooded with high purity argon gas to achieve oxygen content in the chamber below 20 ppm. After the build process was finished, the platform and the samples were cooled down to room temperature with a cooling rate of approximately 5 °C/min. The samples were produced using 700 °C substrate preheating temperature and the SLM parameter sets were chosen based on the results of the previous work using the titanium orthorhombic alloy powder allowing to obtain fully-dense samples.

The produced samples were cut and polished along the build direction (BD) for the microstructural characterization. Mira 3 LMU TESCAN scanning electron microscope (SEM) in backscattered electrons (BSE) mode was utilized to evaluate the microstructures. The phase composition of the powders and the fabricated samples was analyzed with a Bruker D8 Advance X-ray diffraction (XRD) using Cu-K $\alpha$  ( $\lambda$ = 0.15418 nm) irradiation.

The microhardness of the samples was measured using a Buehler VH1150 testing machine with 500g load 10 s dwell time and.

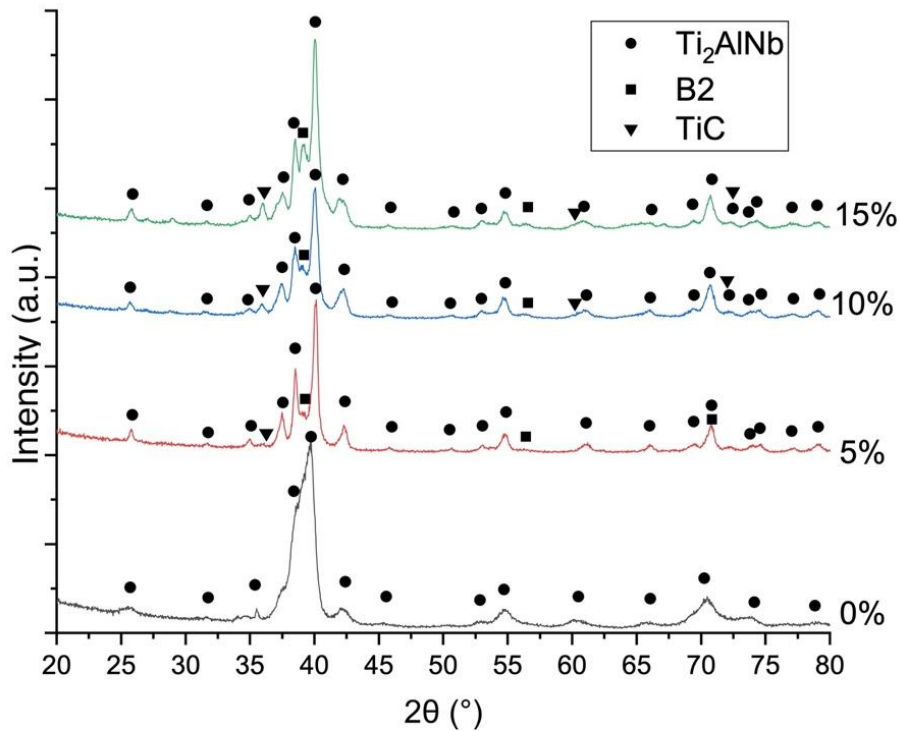
### 3. RESULTS AND DISCUSSION

**Figure 2** shows the microstructure of the samples produced by SLM using SiC/Ti<sub>2</sub>AlNb powder blends with different SiC whiskers volume fraction.



**Figure 2** BSE-SEM-images of the Ti<sub>2</sub>AlNb-based alloy samples fabricated by SLM from SiC/Ti<sub>2</sub>AlNb-alloy powder blend with (a) 0 % (b) 5 %, (c) 10%, and 15% volume fraction of SiC whiskers

When noSiC were added to the titanium orthorhombic alloy powder, the obtained alloy consisted of intermetallic Ti<sub>2</sub>AlNb O-phase. This is accordance with the DSC-data and Ti-22Al-xNb phase diagram [11] since the SLM process took place at 700 °C substrate preheating temperature which corresponds to B2+O phase field close to single O-phase region. Addition of 5 vol% SiC whiskers did not result in precipitation of visible amount of secondary phase. However, primary β-phase grain boundaries became more distinguished. Increasing the volume fraction of SiC in the powder blend decreased the grain size of primary β/B2-phase in the alloy. At the same time, when volume fraction of SiC was increased to 10% secondary phases became more pronounced and according to XRD results (**Figure 3**) TiC phase precipitates formed in the alloy. During the SLM process, SiC whiskers dissociated into Si and C and reacted with the titanium alloy melt resulting in in-situ formation of the secondary strengthening phase. Pure silicon and non-reacted carbon most likely dissolved in the titanium matrix forming a solid solution. Some residual B2/β phase can be seen in the BSE-images in case of 10 and 15 vol% SiC blends. Silicon is a β-stabilizer and increasing its content in the alloy resulted in the formation of β-phase which can be seen in the images as a phase with light contrast. A fine lamellar B2+O microstructure can be seen inside primary β-grains. Further increasing of SiC volume fraction to 15% significantly increased the fraction of TiC phase precipitates that are mostly located at the grain boundaries. At the same time, significant refinement of primary β-phase grains occurred due to introduction of new nucleation sites by addition of SiC whiskers.



**Figure 3** The XRD results of the samples fabricated by SLM using SiC/Ti<sub>2</sub>AlNb powder blends

Addition of SiC whiskers to the Ti<sub>2</sub>AlNb-powder altered the mechanical properties of the obtained alloy. As shown in **Table 1**, microhardness of the alloy significantly increases with addition of SiC whiskers. Addition of 5 vol% of SiC to the powder blend resulted in ~46% increase in microhardness, while addition of 10 vol% SiC increased microhardness of the alloy by ~80% compared to the initial Ti<sub>2</sub>AlNb-based alloy. An increase in microhardness can be attributed to the formation of fine precipitates of TiC phase along with primary β/B2 grain refinement.

**Table 1** Microhardness measurement HV1 results of the samples produced by SLM using SiC/Ti<sub>2</sub>AlNb powder blends

SiC (vol%)	0	5	10	15
Microhardness, HV1	395±10	577±17	701±20	711±15

#### 4. CONCLUSION

In this paper, Ti<sub>2</sub>AlNb-based alloy powder was blended with SiC whiskers and used in Selective Laser Melting process to produce bulk samples. Microstructure, phase composition, and microhardness of the obtained alloys were investigated with regards to SiC whiskers volume fraction.

SLM process of SiC/Ti<sub>2</sub>AlNb powder blend resulted in in-situ reaction of titanium alloy melt with silicon carbide dissociated into Si and C and formation of fine TiC precipitates. Addition of SiC whiskers and formation of secondary phases during the SLM process led to primary β/B2 grain refinement. This resulted in a significant increase in microhardness of the alloy up to 711±15 HV1.

#### ACKNOWLEDGEMENTS

*This research was supported by Russian Science Foundation grant (project No 18-13-00111, <https://rscf.ru/project/18-13-00111/>)*

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