Titanium aluminides for automotive applications processed by electron beam melting

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Abstract

Powders of alloys Ti-48Al-2Cr-2Nb (48-2-2) and Ti-48Al-2Nb-0.7Cr-0.3Si (RNT650) were used to fabricate test samples and turbocharger wheel prototypes, respectively, by electron beam melting. This additive manufacturing technology uses an electron beam to generate parts by selectively melting the powder in a layer-by-layer way based on CAD data. The parts of both alloys were fully densified with only minor percentages of build flaws. For alloy 48-2-2, a loss of Al of about 1.4 wt% is observed, while the levels of impurities are comparable between the powder and the part. Furthermore, the microstructure was investigated after EBM and after EBM + heat treatment for alloy 48-2-2. It is characterized by equiaxed grains after EBM. An additional heat treatment transformed this microstructure into a fully lamellar one showing that the microstructure was homogenized.

1 Introduction

Electron beam melting (EBM®) is a technology for additive manufacturing (AM), which is able to produce metallic components with a high degree of complexity using computer aided design (CAD) data. EBM® is a powder-bed-based technology, which creates high density parts by selectively melting the powder in a layer-by-layer way. Its main features, which make EBM® unique among AM processes, are:

- The use of an electron beam, which is used for two process steps on each powder layer, namely pre-heating and melting. On one hand this helps to reduce thermal stresses, because the build chamber can be held at elevated temperatures during the build process. On the other hand, there is a wide range of materials (e.g. Ti-based alloys, superalloys, intermetallics, refractory metals), which can in principle be fully densified due to the very high energy density.
- The process environment, which is high vacuum (HV). This is a prerequisite to be able to use the electron beam, but is also beneficial for other reasons: (i) highly reactive metals and alloys can be processed, (ii) outgassing of impurities can take place and (iii) a high degree of thermal insulation is provided.
- The beam deflection system, by which scan speeds up to 8000m/s can be realized, which translates into high build rates (e.g. 55- 80 cm^3/h for Ti-6Al-4V [1]) when compared to other AM processes.

γ-TiAl refers to a class of intermetallics, which due to their preferable combination of high mechanical strength and low density have been considered one of the candidate materials to replace Ni-base superalloys e.g. in aero engines (for a detailed description of alloys, processing and properties see [2]). According to a recent review [3] and [4] this goal has been achieved now, as one of these alloys has found its first application in the last stage(s) of the low pressure turbine of the General Electric GEnx aero engine, where cast blades are assembled.

Generally the processing of γ-TiAl involves several steps of very complex thermo-mechanical treatments. Furthermore, additional heat treatments are necessary afterwards in order to tailor the microstructure with respect to the application. EBM provides a promising possibility to produce net-shape parts of these difficult-to-process materials, which might lead to shorter lead times and better material utilization.

γ-TiAl alloys, which were processed by EBM®, have been the subject of previous investigations [5-13]. The most investigated alloy is Ti-48Al-2Cr-2Nb (at%). Generally this alloy can be fully densified by EBM. Furthermore, the microstructure depends on the process parameters, but generally both the γ and α phase are detected in as-EBM samples. Like for other processing routes the microstructure can be tailored through additional thermal treatments.

In this study the aim was the analysis of samples of alloys Ti-48Al-2Cr-2Nb (48-2-2) and Ti-48Al-2Nb-0.7Cr-0.3Si (RNT650) in the form of test samples and turbocharger wheel prototypes.

2 Material and experiments

2.1 Powder and samples

The TiAl powders were produced by gas atomization and has a particle size between 45 – 150µm. Test samples and turbocharger wheels were produced on an EBM machine (model Arcam A2X) with a layer thickness of 70µm. In Figure 1 one exemplary sample placement for the prototype wheels is shown. Different support structures were tested for single and stacked samples (Figure 1).

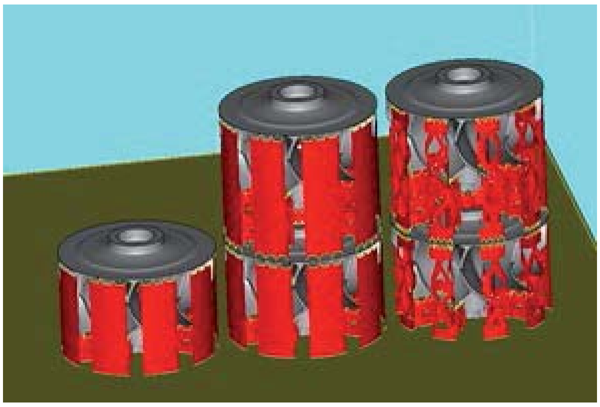

Figure 1: turbocharger prototypes: sample placement within build chamber with different support structures

2.2 Experimental

Test samples and turbocharger wheels have been cut along the longitudinal direction and polished with SiC papers up to 4000 grit in order to observe them by the optical microscope and evaluate the residual porosity.

After porosity evaluation the specimens were etched in Kroll solution (3 ml HF, 6 ml HNO3 in 100 ml H2O) in order to evaluate the microstructure as received after EBM process.

The chemical composition of powder and specimen was measured:

- Al, Cr, Nb, Fe have been detected by ICP
- C, S, N, O have been detected by LECO

3 Results and Discussion

3.1 Alloy 48-2-2

The chemical composition of the specimens has been analyzed and compared with the chemical composition of the powder used for EBM. The results are shown in Table 1.

	Al [wt%]	Cr [wt%]	Nb [wt%]	Ti [wt%]
powder	34.1	2.37	4.78	Bal.
turbocharger	32.7	2.30	4.86	Bal.
	O [wt%]	N [wt%]	C [wt%]	S [wt%]
powder	0.084	0.004	0.006	<0.001
turbocharger	0.079	0.006	0.014	<0.001

Table 1: Chemical composition of powder and specimens by ICP and LECO

As reported in literature [3, 9, 11] an aluminum loss is observed, which with the chosen process parameters is about 1.4 wt%. Furthermore, the pick up of contaminants such as O, C, N is very low due to the vacuum environment in the working chamber.

The porosity percentage of the turbocharger obtained results to be less than 1%. Two kind of residual defects have been detected in the first set of samples:

- spherical pores which can reach a maximum size of about 50 µm (see Figure 2). This kind of porosity is attributed to powder defects and can be considered acceptable.
- bigger elongated (100 µm) pores (see Figure 3). This kind of porosity is attributed to the process and can be avoided by parameters optimization

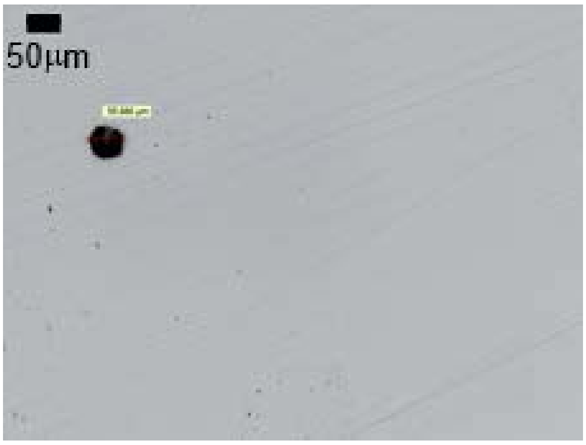

Figure 2: porosity alloy 48-2-2 (spherical pore)

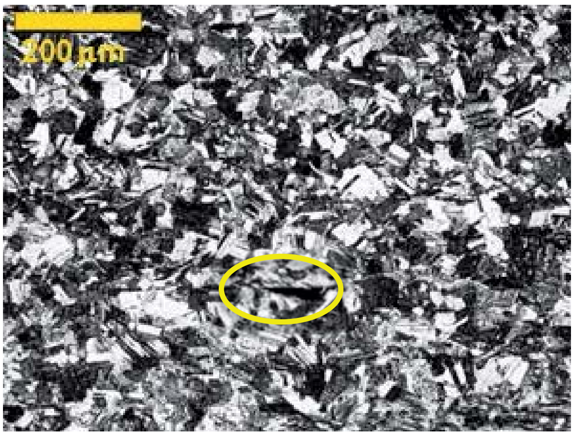

Figure 3: porosity alloy 48-2-2 (elongated pore)

In Figure 4 the sectioned turbocharger can be seen and in particular the details of the microstructure of 3 zones are shown in detail:

- Zone 1 the core of the turbocharger
- Zone 2 the external part of the turbocharger
- Zone 3 the thin part of the wheel blade

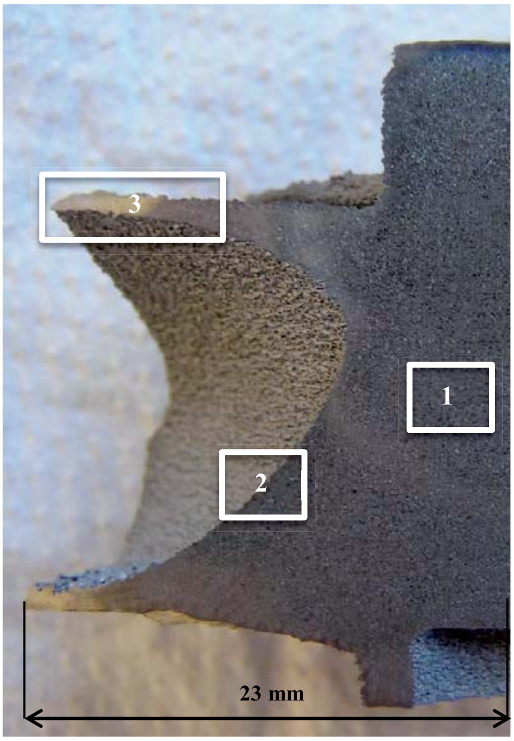

Figure 4: Sectioned turbocharger wheel

The detail of the core of wheel (zone 1) is given in Figure 5. The microstructure is made of very fine equiaxed grains containing some coarser equiaxed ones. In particular it is evident that the coarser grains are organized in bands, which are orientated parallel to the powder layers during EBM process (these bands are perpendicular to the growing direction of the specimen given by the white arrow).

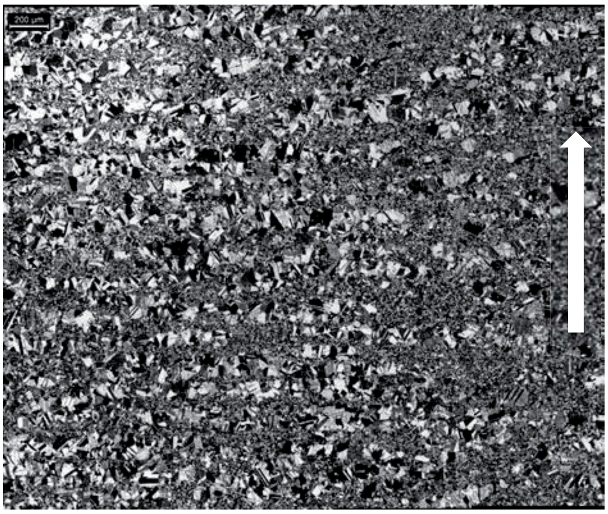

Figure 5: microstructure at the core of the turbocharger

The detail of zone 3 at progressive increasing of magnifications is given in Figure 6 and confirms the presence of the same kind of microstructure in the thin wheel blades too.

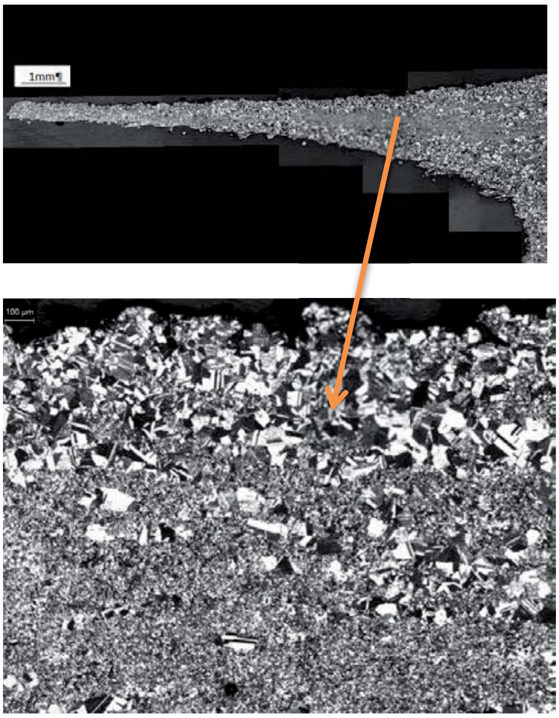

Figure 6: microstructure at the thin part of the wheel blade

The detail of Zone 2 is given in figure 7 and exhibits the presence of a contour of about 600 micron (indicated by the arrow 1) slightly different in microstructure with respect to internal part (arrow 2).

However the roughness of the specimen after EBM, expressed in terms of Ra, is around 30-40 micron suggesting that machining is necessary. For this reason the presence of this contour in the specimen can be avoided since it will be removed by machining.

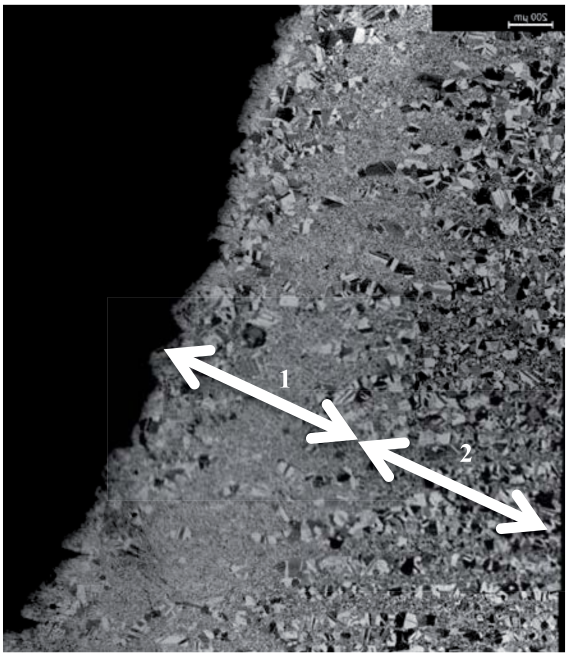

Figure 7: microstructure at the external part of the turbocharger

An additional heat treatment (1315°C, 2h) was performed in order to develop a fully lamellar microstructure in the specimen. In Figures 8 and 9 it can be seen that the inhomogeneities (fine and coarse grains) are completely recovered and a homogeneous fully lamellar microstructure is obtained both in the core of the specimen and at thin wheel blades.

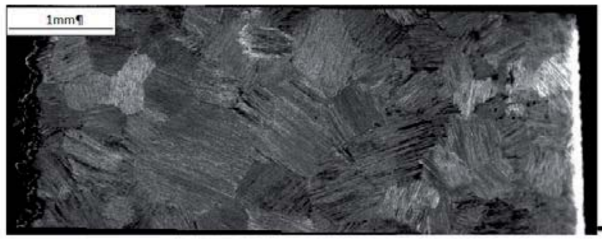

Figure 8: microstructure at the core of the turbocharger after heat treatment

Figure 9: microstructure at the thin part of the wheel blade after heat treatment

3.2 Alloy RNT650

As this alloy has not been processed by EBM, only test samples (cubes with a volume of 1000mm³) were produced in the first build trials. On these samples investigations were done in order to assess porosity and microstructural features.

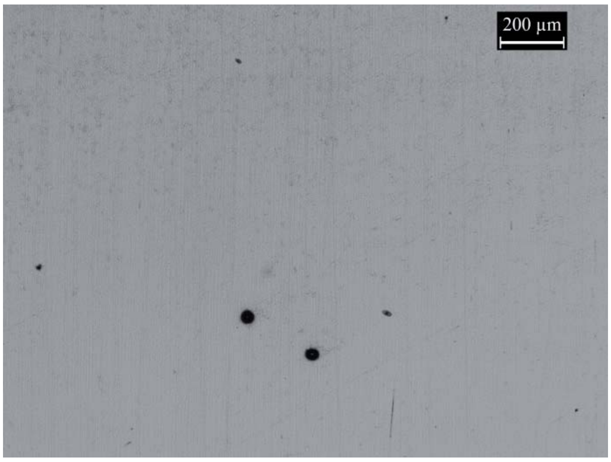

Figure 10: porosity alloy RNT650 (spherical pore)

In terms of porosity, the measured value is less than 0.1%, indicating full densification of the samples. In Figure 10 spherical pores are shown, which are observed for this alloy as well.

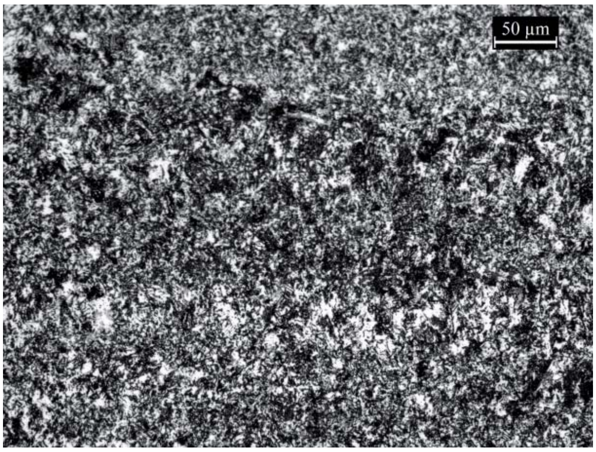

Figure 11: microstructure alloy RNT650 (as EBM)

An example of the microstructure after the EBM process is shown in Figure 11. Similarly to alloy 48-2-2 a predominantly fine-grained equiaxed microstructure is observed. Furthermore, bands of coarse equiaxed grains are detectable as well, which are perpendicular to the build direction but the overall microstructure is even more homogeneous than previous specimens made of 48-2-2.

4 Summary and Conclusions

Turbocharger wheel prototypes made of alloy Ti-48Al-2Cr-2Nb were produced by electron beam melting. The parts were fully densified with only a minor amount of build flaws. The observed loss of Al was in the range of 1.4wt%, while the impurity contents are comparable between the powder and the part indicating the cleanliness of the process. The microstructure in the as-EBM and heat-treated state was analysed. Directly after EBM the microstructure consists of equiaxed coarse and fine grains. The distribution of the two fractions depends on the location within the wheel with distinct differences between the internal and external parts. An additional heat treatment homogenized the microstructure to fully lamellar. Furthermore, first test samples of alloy Ti-48Al-2Nb-0.7Cr-0.3Si were produced. Also these samples were fully densified. Similarly to alloy Ti-48Al-2Cr-2Nb the microstructure after EBM consists of equiaxed coarse and fine grains.

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6 Literature

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