

Properties of a TiAl Turbocharger Wheel Produced by Electron Beam Melting

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Abstract

Powder of alloy Ti-48Al-2Cr-2Nb was used to fabricate turbocharger wheel prototypes 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 were fully densified with only minor percentages of build flaws. 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. 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 cm³/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 alloy Ti-48Al-2Cr-2Nb in the form of turbocharger wheel prototypes.

2 Material and experiments

2.1 Powder and samples

The TiAl powder was produced by gas atomization and has a particle size between 45 – 150 μ m. Turbocharger wheels were produced on an EBM machine (model

Arcam A2X) with a layer thickness of 70 μm . In Figure 1 one exemplary sample placement is shown. Different support structures were tested for single and stacked samples (Figure 1).

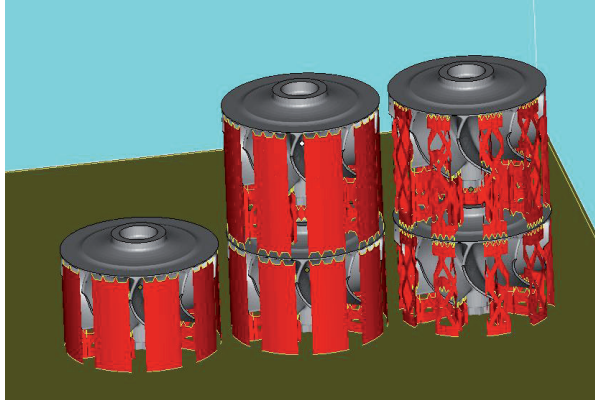


Figure 1: turbocharger prototypes: sample placement within build chamber with different support structures

2.2 Experimental

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

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

Table1: 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

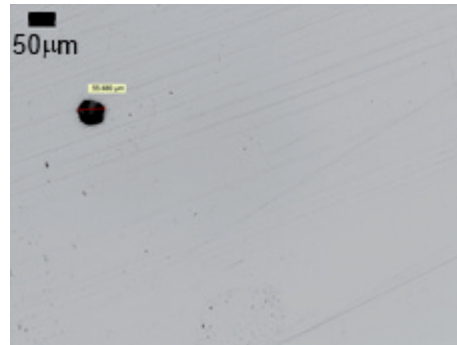


Figure 2: Spherical pore

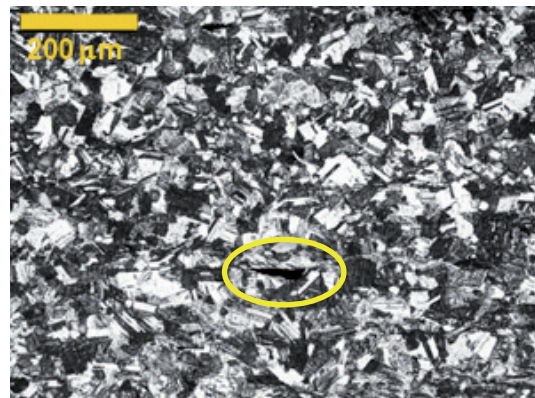


Figure 3: Elongated pore

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

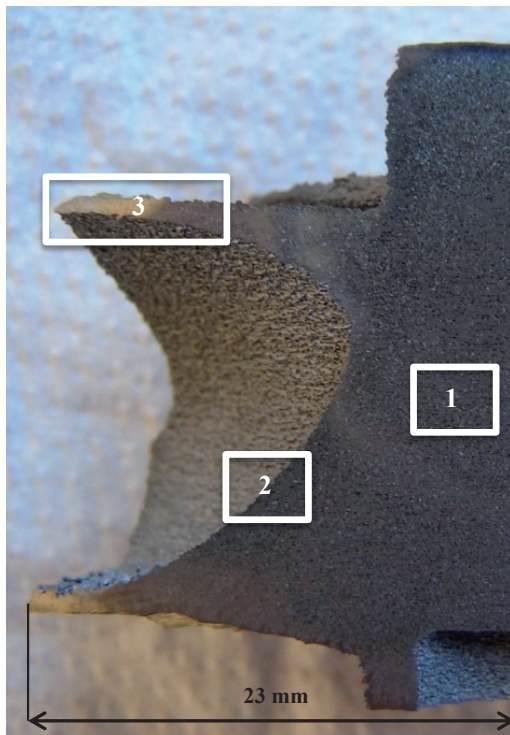


Figure 4: Sectioned turbocharger wheel

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).

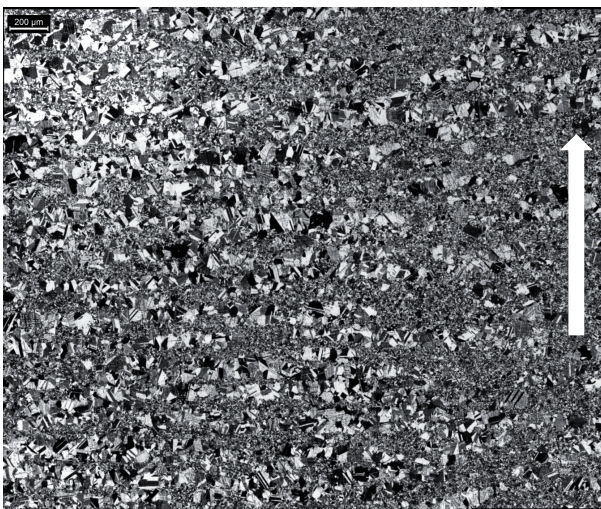


Figure 5: microstructure at the core of the turbocharger

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

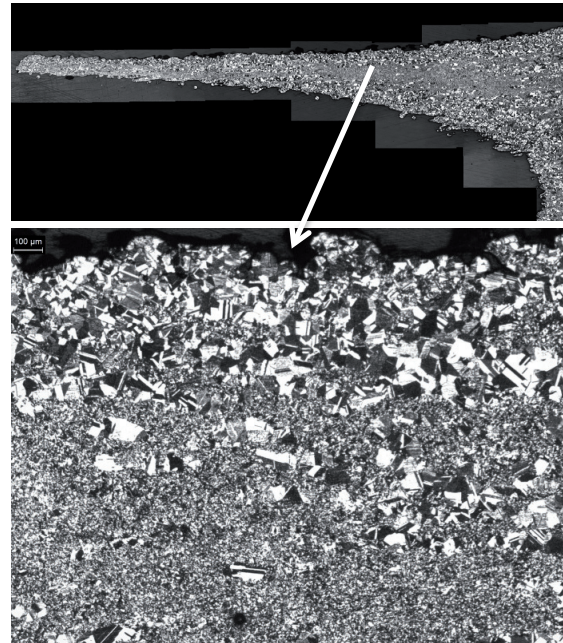


Figure 6: microstructure at the thin part of the wheel blade

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 R_a , 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.

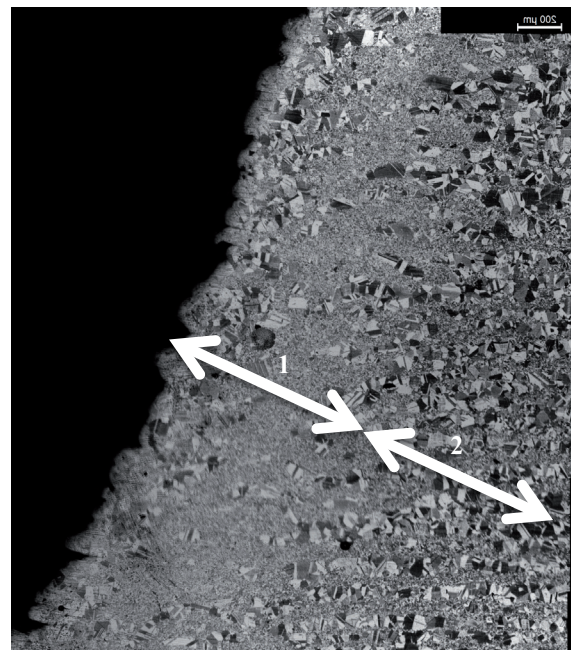


Figure 7: microstructure at the external part of the turbocharger

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.

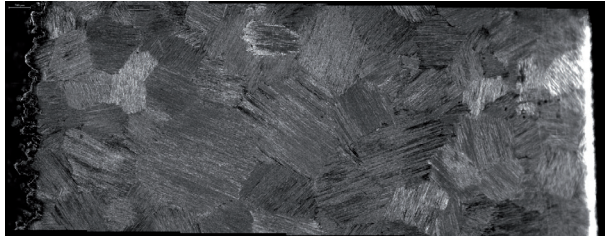


Figure 8: microstructure at the core of the turbocharger after heat treatment

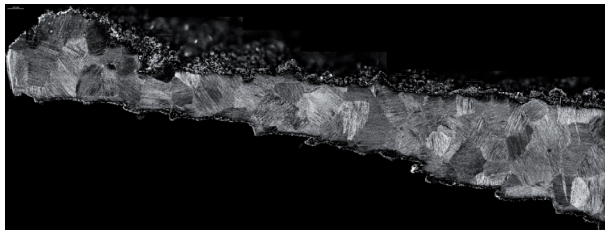


Figure 9: microstructure at the thin part of the wheel blade after heat treatment

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.

Acknowledgements

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Literature

- [1] Arcam A2 machine description. Available at: <http://www.arcam.com/wp-content/uploads/Arcam-A2.pdf>.
- [2] F. Appel, J. D. H. Paul, M. Oehring "Gamma Titanium Aluminide Alloys", Wiley VCH, 2011
- [3] H. Clemens and S. Mayer, "Design, Processing, Microstructure, Properties and Applications of Advanced Intermetallic TiAl Alloys", *Adv. Eng. Mater.*, vol. 15, no. 4, 2013, pp. 191-215.
- [4] B.P Bewlay, M. Weimer, T. Kelly, A. Suzuki and P.R. Subramanian, "The Science, Technology and Implementation of TiAl Alloys in Commercial Aircraft Engines", *MRS Proceedings*, vol. 1516, 2013, pp. 49-58.
- [5] D. Cormier, O. Harrysson, T. Mahale and H. West, "Freeform Fabrication of Titanium Aluminide via Electron Beam Melting using Prealloyed and Blended Powders", *Research Letters in Material Science*, 2007, pp. 1-4.
- [6] S. Sabbadini, O. Tassa, P. Gennaro and U. Ackelid, "Additive Manufacturing of Gamma Titanium Aluminide Parts by Electron Beam Melting", *TMS Supplemental Proceedings: Materials Processing and Properties*, vol. 1, 2010, pp. 267-274.
- [7] L.E. Murr et al., "Characterization of titanium aluminide alloy components fabricated by additive manufacturing using electron beam melting," *Acta Mater.*, vol. 58, 2010, pp. 1887-1894.
- [8] S.F. Franzén, J. Karlsson, "An Investigation of Microstructural Behaviour and Related Mechanical Properties for Aerospace Applications", Diploma work 37/2010, Chalmers University of Technology, 2010.
- [9] S. Biamino et al., "Electron beam melting of Ti-48Al-2Cr-2Nb alloy: Microstructure and mechanical properties investigation", *Intermetallics*, vol. 19, 2011, pp. 776-781.
- [10] Loeber et al., "Comparison of Selective Laser and Electron Beam Melted Titanium Aluminides", in *Solid Freeform Fabrication Proceedings*, 2011, pp. 547-556.
- [11] S. Biamino et al., "Electron beam Melting of High Niobium Containing Alloy: Feasibility Investigation", *Steel Research International*, vol. 83, no. 10, 2012, pp. 943-949.
- [12] J. Hernandez, L.E. Murr, S.M. Gaytan, E. Martinez, F. Medina and R.B. Wicker, "Microstructures for Two-Phase Gamma Titanium Aluminide Fabricated by Electron Beam Melting", *Metallogr. Microstruct. Anal.*, vol. 1, 2012, pp. 14-27.
- [13] A. Penna, "γ-TiAl Fabricated by EBM as Innovative Material for Aerospace Applications with Low Environmental Impact", PhD thesis, Politecnico di Torino, 2013.