On the Evolution of Banded Microstructures in an Electron Beam Melted Ti-48Al-2Cr-2Nb Alloy

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Motivation

Intermetallic γ-TiAl based alloys offer outstanding creep properties, high specific strength and sufficient oxidation resistance at application temperatures in the range from 600 to 800 °C[1]. These properties make them prosperous candidates to substitute heavy Ni-based alloys offering weight savings up to 50%[2,3]. Drawbacks include their inherent brittleness as well as their reactive melt, which complicate processing and drive costs[4]. Electron beam melting (EBM), a powder bed based additive manufacturing technology, offers low impurity pickup due to the vacuum environment and elevated processing temperature, enabling the manufacturing of TiAl components with increased geometrical complexity[5]. Still, the microstructure of electron beam melted titanium aluminides often shows a banded character and suffers from Al loss due to process related evaporation, thus, decreasing room temperature ductility[6,7]. As the formation mechanism of banded microstructures in electron beam melted Ti-48Al-2Cr-2Nb (in at. %, unless stated otherwise) is not yet fully understood, an explanation is presented in this work.

Experimental Procedure

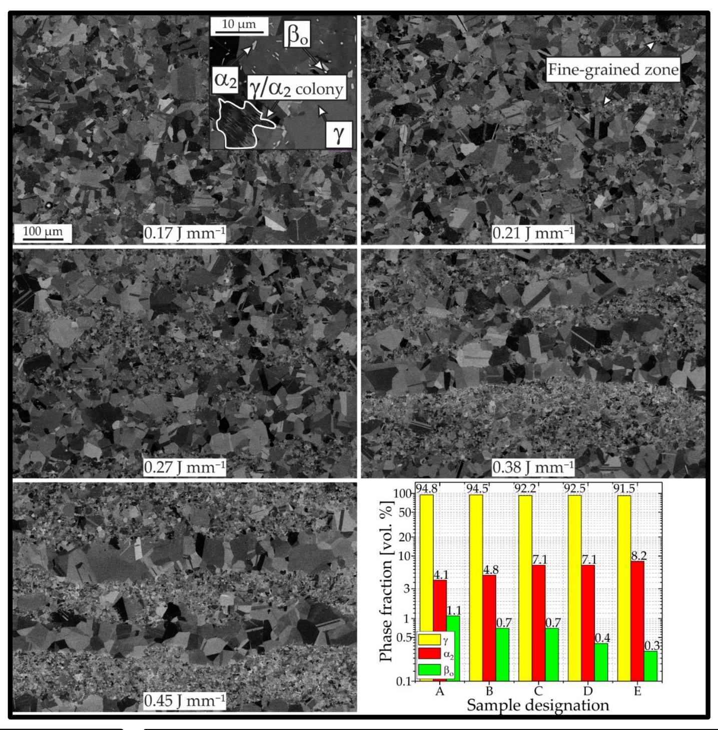
Five samples of a Ti-48Al-2Cr-2Nb alloy were manufactured by EBM with a specific set of different processing parameters. Microstructures, phase composition as well as chemical distribution were investigated by scanning electron microscopy, X-ray diffraction and electron backscatter diffraction. In addition, electron probe microanalysis was used to investigate the chemical distribution of aluminum. Location-dependent mechanical properties with regard to the processing history were studied by micro-hardness testing. All results were compared to a vertical section of the Ti-Al-Cr-Nb alloy system obtained by thermodynamic equilibrium calculations where the phase transformation temperatures were verified by thermomechanical analysis. Numerical simulations via a developed 3D FE thermal model[8] were performed for additional insights on the microstructure – processing relationship. Finally, heat treatments are presented to elaborate on the influence of the processing parameters.

Influence of Process Parameters

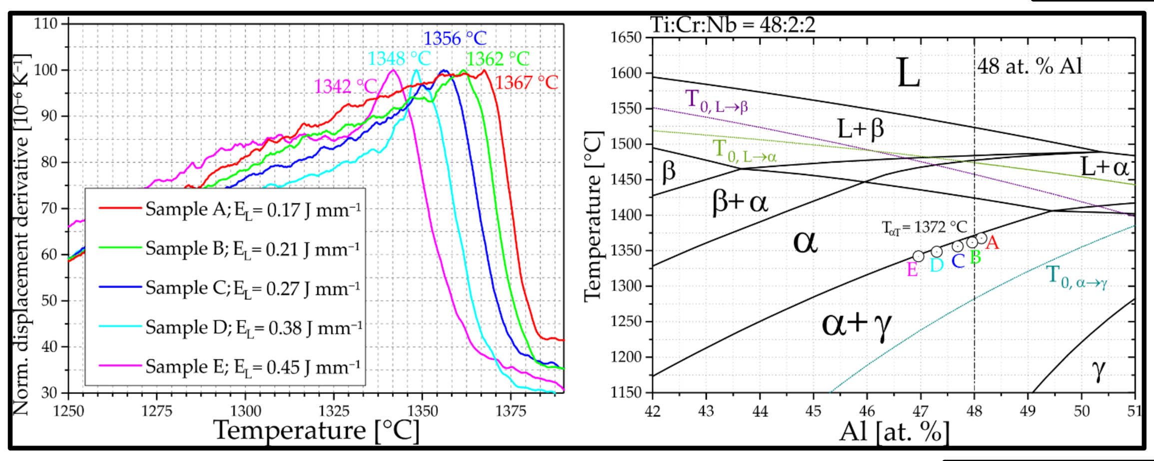
All samples revealed near-γ microstructures consisting of γ-TiAl, α_2-Ti_3Al and β_o-TiAl due to the intrinsic long-term annealing during the EBM process.

With increasing energy input...

…fine grained duplex and lamellar regions of γ and α_2 appear in the microstructure in a banded fashion.

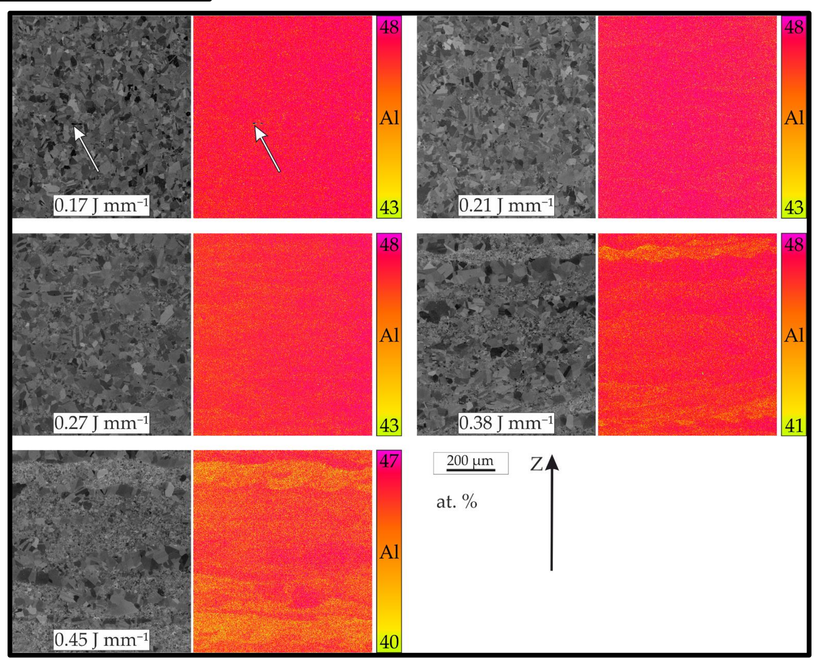


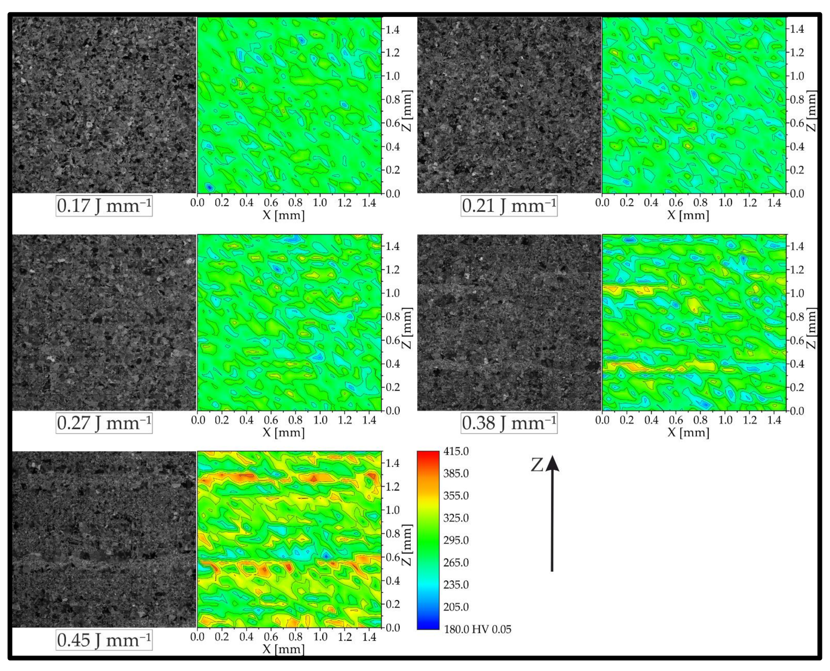
…the phase fraction of α_2 increases with decreasing γ content.



…the α-transus temperature decreases, which is explainable by a larger loss of Al due to evaporation.

…the amount of Al evaporation increases considerably and the Al distribution becomes inhomogeneously banded.

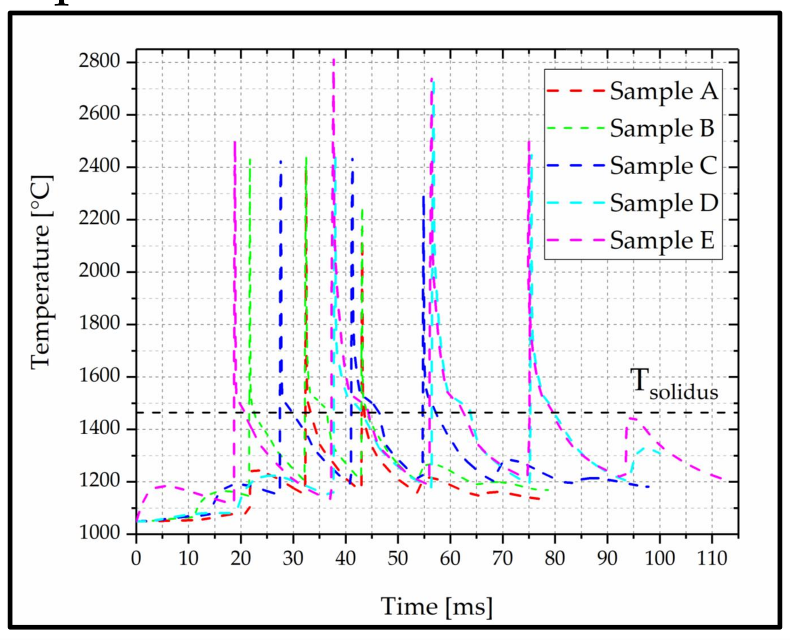


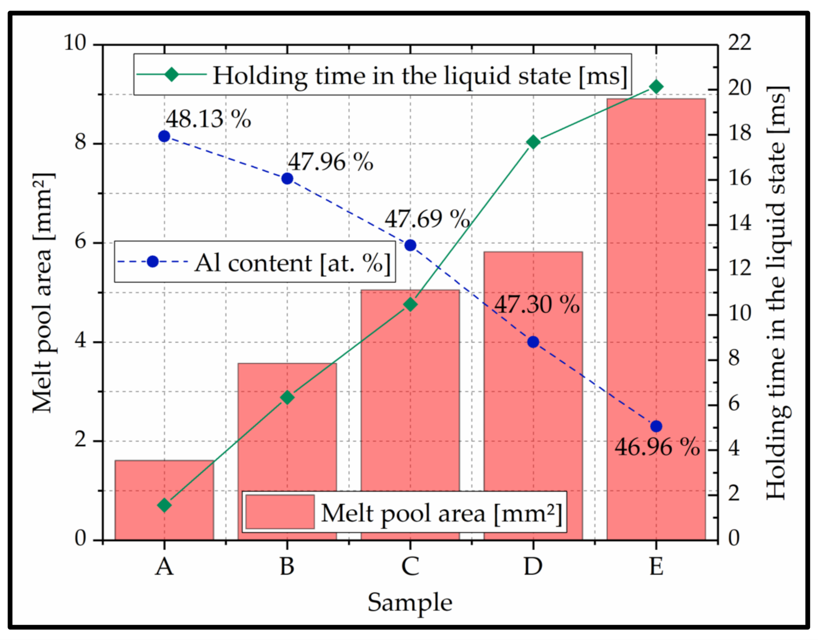


…the macroscopic hardness increases extensively (up to 18%) and the microscopic hardness shows banded regions of high hardness due to the smaller grain size and higher amounts of α_2.

Numerical Simulation

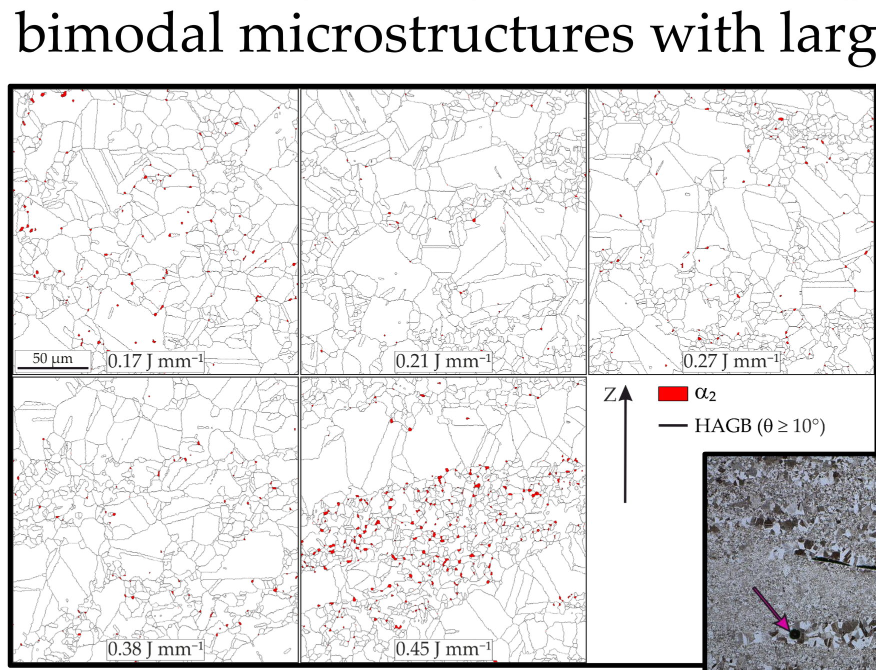
Increasing the energy input leads to longer holding times in the liquid state, higher maximum temperatures, larger melt pool sizes and more remelting events, which increased the amount of Al evaporation.

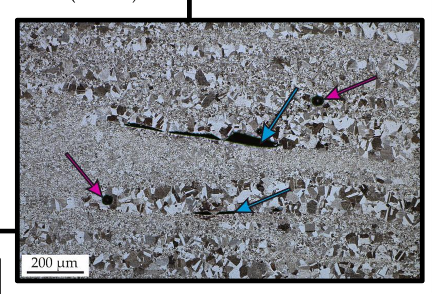


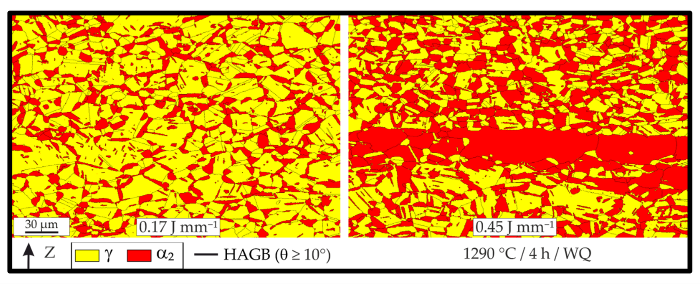


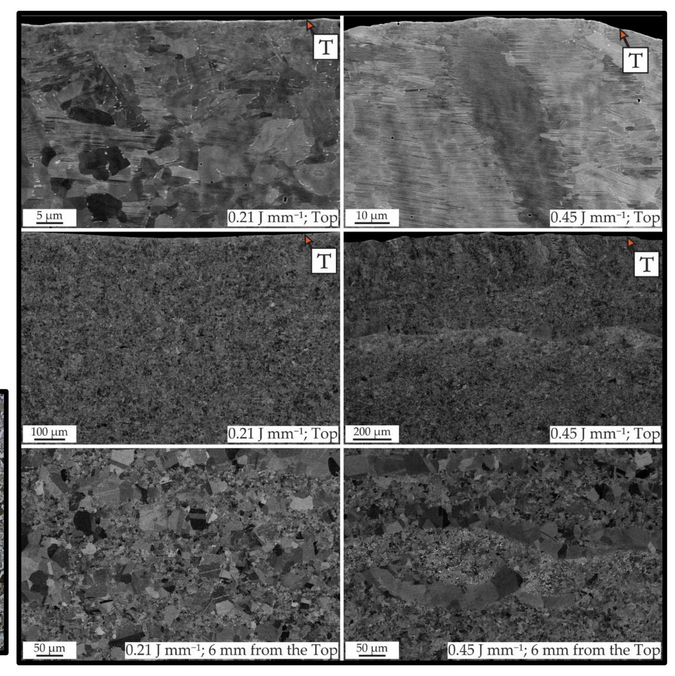
Formation Mechanism

As a consequence of the inhomogeneous Al distribution, α_2 preferably dissolves in Al-rich zones during the long-term annealing under formation of the near-γ microstructure. Subsequently, abnormal grain growth takes place in Al-rich zones leading to bimodal microstructures with large γ-grain bands.









Banded microstructures form colony bands during subsequent heat treatments.

Conclusions

- Process-related heterogeneous Al distribution is the reason for the formation of banded microstructures due to the long-term intrinsic annealing during EBM at the building temperature due to abnormal grain growth of γ-grains in Al-rich zones.
- The formation of banded microstructures can be prevented by choosing process parameters with decreased energy input.

Literature

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