Electron Beam Melting of Pure Copper – From Research to Industrialization

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Abstract: *The Additive Manufacturing technology Electron Beam Melting shows high potential in processing pure copper for high conductivity applications. Pure copper powder was consolidated, and process parameters were optimized. It is feasible to manufacture components with a relative density >99.5 %, an electrical conductivity > 57 MS/m, an ultimate tensile strength >175 MPa and with an elongation at fraction of >35 %. With those physical properties, high performance applications like heat exchangers, induction coils and electrification components can be additively manufactured with EBM.*

Keywords: Additive Manufacturing; pure copper; powder; Electron Beam Melting; electrical conductivity; mechanical properties

Introduction

Electron Beam Melting (EBM) belongs to the powder-based Additive Manufacturing (AM) techniques and describes a method of generating complex geometries layer-by-layer. Therefore, a powder layer of a defined thickness is applied and afterwards selectively melted by an electron beam energy source. The single layer production ends by lowering of the build platform and then a new layer is applied.

Compared to laser based AM devices, EBM provides technological advantages for processing high-performance materials like titanium, titanium alloys, titanium aluminides or crack prone nickel alloys and is entrenched in the area of aerospace - and medical engineering.

Beside those well-established materials, the EBM technology facilitates additive manufacturing for multiple other metal alloys. During the last few years, high conductivity copper applications came into focus of the additive community. In 2020, GE Additive will release a Pure Copper EBM process, classified as development material maturity (D-material). This contribution set out the current process capabilities of EBM manufacturing with pure copper for exemplary applications.

Pure copper is a soft and high density metal with excellent thermal and electrical conductivities. However, copper is challenging to process with the laser-based technology and requires excellent process control. Conventional 1064 nm wavelength laser shows very low absorption (<5 %), often resulting in porous samples [1]. In contrast, the energy absorption rate of EBM is around 80 % for pure copper [2]. Beside the effective melting, the high purity vacuum atmosphere allows processing copper at elevated temperatures without risk of oxidation. This significantly minimizes residual stresses during manufacturing, whereby the component distortion and crack initiation can be suppressed.

Experimental setup

For process development, a gas atomized, spherical pure copper powder (Cu >99.95 wt%) with a particle size distribution from 45 µm to 105 µm was used. The development was focused on powder with low oxygen (< 0.02 wt%) and low phosphorous (<0.005 wt%) content.

The process development was conducted on an Arcam Q10plus platform (EBM Control 5.3). During material consolidation, a so called constant current scan strategy was applied, offering the advantage of minimizing geometry dependency. The process temperature is in the range of 300-450 °C.

Results

With the constant current scan strategy, a process window for dense samples >99.5 % and smooth component surfaces was developed. The microsection in Figure 1 depicts minor defects like gas pores, which can further be reduced during process industrialization if required.

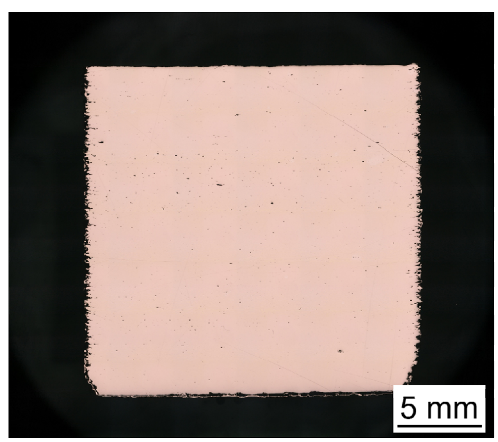

Figure 1. Polished microsection of additively manufactured pure copper via EBM. Cut along the build direction.

Electrical conductivity measurements are performed at sample microsections, such as shown in Figure 1, with an eddy current system and a 60 kHz probe, according ASTM 1004. Figure 2 shows the correlation between the conductivity expressed as percent of the International Annealed Copper Standard (IACS) and the relative density of the samples. A high relative density of > 99.5 % results in an electrical conductivity above 57 MS/m. Conversely, an increasing number of defects, e.g. lack of fusion, the electrical conductivity decreases, and the results also display more scattering. It can be assumed, that the parameters changed in the DOE results in different defect structures and therefore different conductivity results.

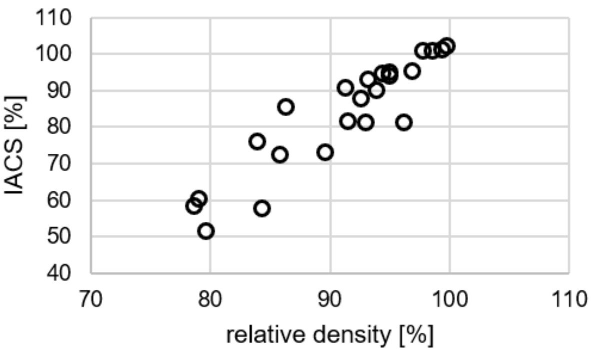

Figure 2: Electrical conductivity (IACS) vs. the relative density. (100 % IACS = 58 MS/m).

The mechanical properties in Table 1 depict the lower limit for the ultimate tensile strength and elongation at break for copper at room temperature, as measured for dense samples. The tensile test is conducted according to ASTM E8

Table 1: Minimum mechanical properties at room temperature.

Ultimate Tensile Strength (MPa)	Elongation at Break (%)
> 175	> 35

Figure 3 displays manufactured components of three exemplary applications for EBM with pure copper. Also conceivable are complex antennas, meta materials or wave guides.

a) Heat exchanger **b) Induction coil** **c) Electrification component**

Figure 3: Additively manufactured exemplary applications for pure copper, produced by EBM. a) Freedom in design for complex geometries and excellent thermal conductivity. b) Combined parts with increase lifetime and excellent electrical conductivity. c) Complex geometries at competitive cost with excellent electrical conductivity.

Conclusion

EBM shows its technological potential in processing pure copper. The results demonstrate applicability for various fields of use and a huge potential regarding productivity (melt rate up to 70 cm³/h demonstrated) and achievable conductivity (>100 % IACS demonstrated). Further development during customer specific process industrialization can cut down remaining porosity and maximize productivity.

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