

Impurity Behavior in Cast Copper Anodes: Implications for Electrorefining in a Circular Economy

Agustin Morales-Aragon, Daniel Sánchez-Rodas, Guillermo Ríos and Michael S. Moats

SUPPLEMENTARY INFORMATION

Anodes

Each of 13 blocks received from the Institute for Process Metallurgy and Metal Recycling (IME RWTH, University of Aachen, Germany) has a dimension of 19 x 21.5 cm (Figure S1). All blocks were shipped for cutting into pieces as shown in the diagram of Figure S2. These pieces were cut using waterjet to not affect the internal structure of the anode for overheating.



Figure S1. Anode block received for cutting into pieces.

The dimensions selected were based on the electrorefining design for the anodes (blue blocks, Figure S2), probes for EPMA, FESEM and Optical microscopy analysis (Green blocks, Figure S2), OES analysis (yellow blocks, Figure S2) and ELTRA analysis for O₂ and S content (purple blocks, Figure S2).

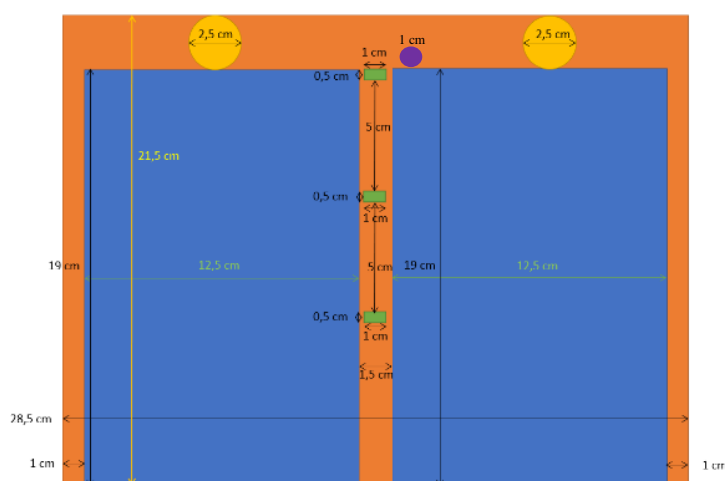


Figure S2. Anode block design for cutting into pieces. Blue rectangular pieces were used for electrorefining. Yellow round pieces were used for OES analysis. Green rectangular pieces were used to analyze the internal structure of the anodes by EPMA, FESEM and Optical microscopy. Purple round piece was employed for O₂ analysis by ELTRA.

Microscope Analysis

Probes were prepared using the procedure shown Table S1.

Table S1. Sanding and polished steps for probes analyzed by Microscopy.

Steps	Sanding /cloth	Grain size	Time (min.)	Rotational velocity (rpm)
Sanding step 1	Sanding 320GRIT 39638-040-320	SiC 320 GRIT	2	250 CW
Sanding step 2	Sanding 600GRIT 39638-040-600	SiC 600 GRIT	2	250 CW
Sanding step 3	Sanding 1200GRIT 39638-040-1200	SiC 1200 GRIT	2	250 CW
Sanding step 4	Sanding 2500GRIT 39638-040-2500	SiC 2500 GRIT	2	250 CW
Polished step 1	WOOL 3 microns 39639-095-250	Diamond susp. 3 microns	3	150 CW
Polished step 1	FEDO-1S 39639-066-250	Diamond susp. 1 microns	2	150 CW
Final Polished	COLLO 39639-085-250	Coloidal	1	50 CW
Final Polished	COLLO 39639-085-250	Coloidal	1	50 CW

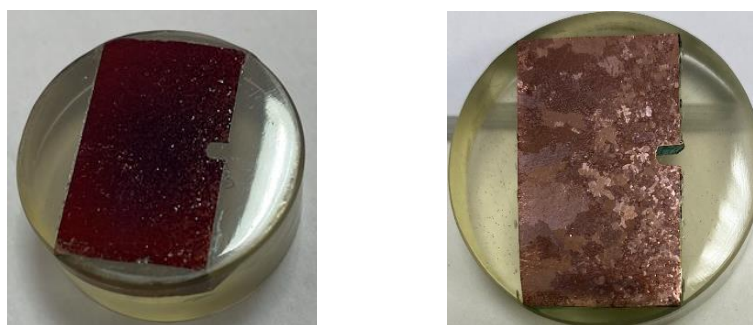


Figure S3. Probe generated for Electron Microscopy analysis (left) and after etching (right) with 100 ml H₂O, 25 ml HCl 37% and 5 g FeCl₃ for grain size analysis by Optical Microscopy.

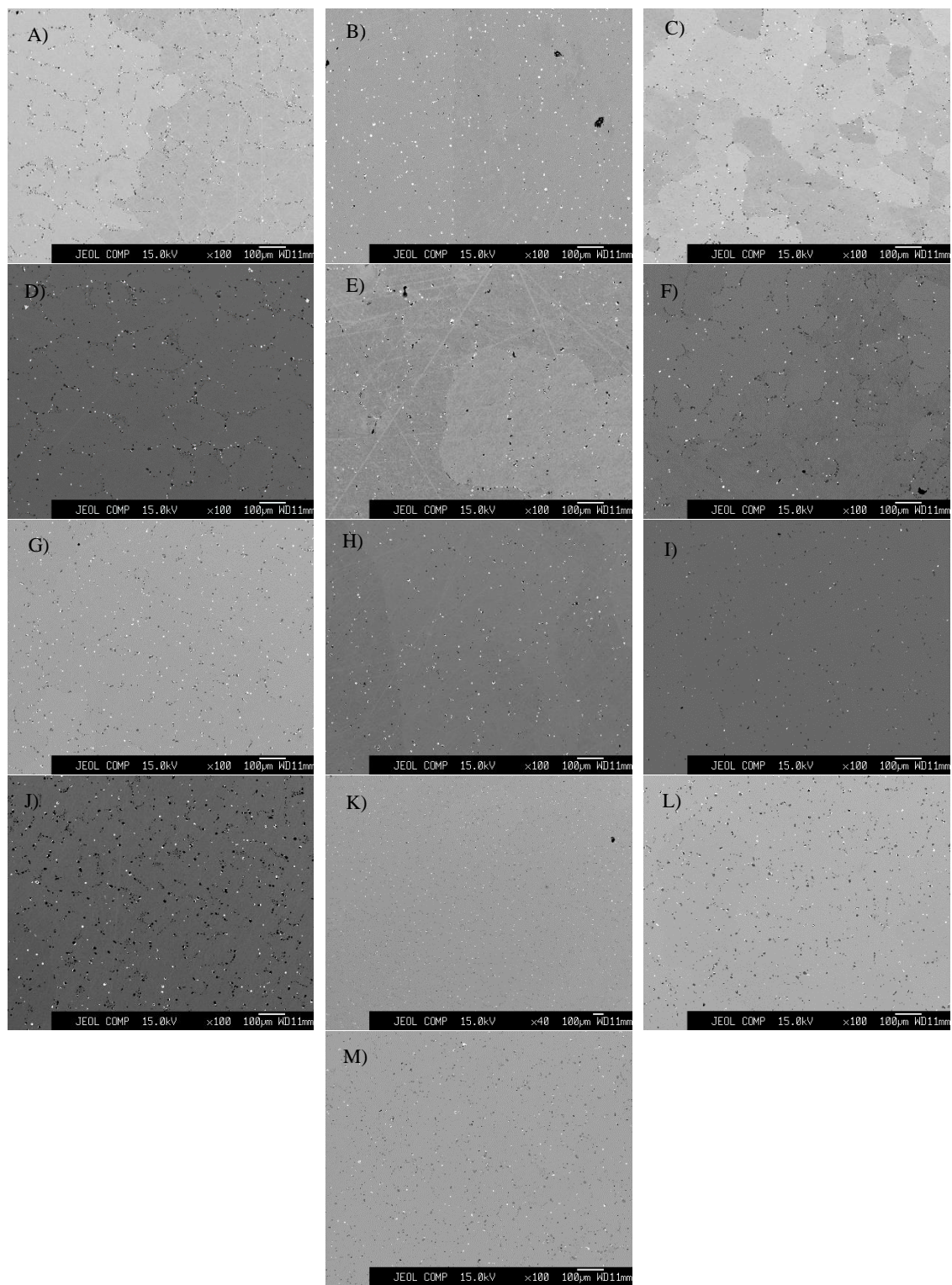


Figure S4. Backscattered electron micrograph showing the general structure of doped anodes. A) DA1; B) DA2; C) DA3; D) DA4; E) DA5; F) DA6; G) DA7; H) DA8; I) DA9; J) DA10; K) DA11; L) DA12; M) DA13.

Table S2 Impurity content in solid solution (wt.%) of commercial (AC1 and AC2) and doped (DA1 to DA13) anodes. 30 Cu grains were analyzed for each doped anode. For Ni, range min-max and mean values in brackets are included. For the rest of the elements, only maximum values are shown, as minimum values and means are below the limits of detection (LD), are in wt.%. As 0.05; Ni 0.04; Sb 0.03; Sn 0.04).

Anode	Ni	Sb	As	Sn
AC1	0.08 – 0.15 (0.11)	<LD	0.1 (0.02)	0.06 (0.02)
AC2	0.07 - 0.21 (0.13)	<LD	0.07 - 0.16 (0.16)	0.05 (0.01)
DA1	0.18 – 0.50 (0.36)	<LD	0.20 (0.03)	0.09 (0.01)
DA2	0.25 – 0.41 (0.35)	<LD	0.22 (0.04)	<LD
DA3	0.23 – 0.47 (0.35)	<LD	0.19 (0.06)	0.08 (0.01)
DA4	0.34 – 0.86 (0.56)	<LD	0.13 (0.04)	0.07 (0.01)
DA5	0.33 – 0.72 (0.47)	<LD	0.10 (0.03)	<LD
DA6	0.22 – 0.44 (0.34)	<LD	0.13 (0.04)	0.08 (0.01)
DA7	0.23 – 0.47 (0.35)	<LD	0.13 (0.03)	0.09 (0.02)
DA8	0.24 – 0.47 (0.36)	<LD	0.09 (0.02)	<LD
DA9	0.20 – 0.42 (0.33)	<LD	0.14 (0.03)	<LD
DA10	0.37 – 0.83 (0.57)	<LD	0.21 (0.10)	0.09 (0.01)
DA11	0.39 – 0.87 (0.58)	<LD	0.09 (0.03)	0.08 (0.02)
DA12	0.25 – 0.78 (0.50)	<LD	0.11 (0.02)	<LD
DA13	0.49 – 0.99 (0.68)	<LD	0.22 (0.10)	<LD