Supplementary material for: **Refining of Secondary Pb with Retention of Sn using Al and Ca Additions**.

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Table S-I. Element composition of lead used for laboratory research (wt. %).

Year	Title	Description
1934	**(Patent)** Method of purifying lead, tin, and lead-tin alloys [1]	The present invention relates to methods of purifying lead, tin, and lead-tin alloys and particularly for the removal of copper, arsenic, and antimony from lead, tin, and lead-tin alloys using aluminum.
2009	Interaction of aluminum with admixtures dissolved in liquid lead [2]	The lead refining with application of aluminum results in a decrease in the contents of antimony and copper.
2013	Alternative method for copper removal from lead by application of aluminium [3]	The lead refining with application of aluminum results in a decrease in the contents of copper.
2018	**(Patent)** Process method for producing low-tin-lead-calcium alloy by utilizing waste grid mesh of waste lead-acid storage battery [4]	Application of Al-Ca mixture for removal of antimony and arsenic from lead while preserving tin.
2018	**(Patent)** Process method for producing high-tin-lead-calcium alloy by utilizing waste lead grid mesh of waste lead-acid storage battery [5]	Application of Al-Ca mixture for removal of antimony and arsenic from lead while preserving tin
2020	New Technology for Copper Removal from Lead by Application of Aluminium: Practical Problems [6]	Industrial-scale studies of lead refining using aluminum for copper removal are presented.
2021	**(Patent)** Process method for producing low-tin lead-calcium alloy by using waste lead-acid storage battery waste lead grid [7]	Application of Al-Ca mixture for removal of antimony and arsenic from lead while preserving tin.
2023	Recovery of Pure Lead-Tin Alloy from Recycling Spent Lead-Acid Batteries [8]	Industrial-scale studies of lead refining using aluminum for antimony, arsenic, copper, nickel, tellurium removal are presented.

Table S-II. Element composition of lead used for laboratory research (wt. %).

Element	Sn	Sb	As	Cu	Se
Content	1.46±0.05	1.51±0.04	0.15±0.01	0.12±0.02	0.11±0.02

Element	Ni	Te	Bi	Ag
Content	0.011±0.002	0.062±0.005	0.0154±0.0005	0.0031±0.0003

Element	Cd	Tl	Ca	Al
Content	0.00062±0.00008	0.0032±0.0001	0.00001±0.00003	0.00001±0.00009

Element	Pb
Content	96.537

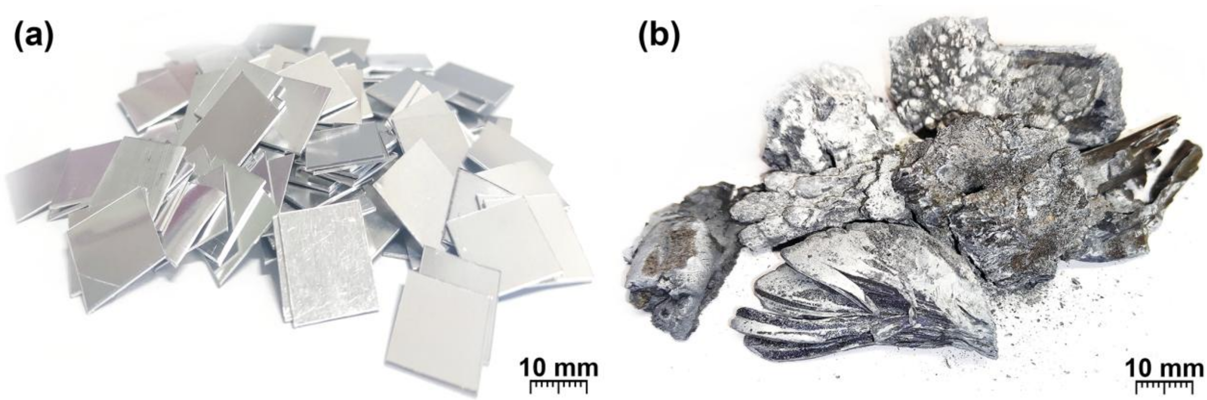

Fig. S-1. (a) Aluminum, which was added to lead as a refiner, was in the form of plates measuring 15 x 20 mm and 0.5 mm thick. (b) Contaminant removal rate for each of the three trials.

Table S-III. Elemental composition of metallic aluminum (Fig. S-1a) used for laboratory research (wt. %).

Element	Fe	Si	Zn	Cu	Ni
Content	0.15±0.04	0.02±0.01	0.011±0.007	0.002±0.001	0.002±0.001

Element	Mg	Cr	S	Pb
Content	0.001±0.001	0.001±0.001	0.001±0.001	0.001±0.001

Element	As	Sn	Al
Content	< 0.0001	< 0.0001	>98.8

Table S-IV. Elemental composition of metallic calcium (Fig. S-1b) used for laboratory research (wt. %).

Element	Al	Mg	Mn	Fe	Cu
Content	0.25±0.05	0.65±0.08	0.009±0.003	0.007±0.001	0.008±0.001

Element	Ni	Na	As	Sn
Content	0.004±0.002	0.02±0.01	< 0.0001	< 0.0001

Element	Pb	Se	Ca
Content	< 0.0001	< 0.0001	>98.7

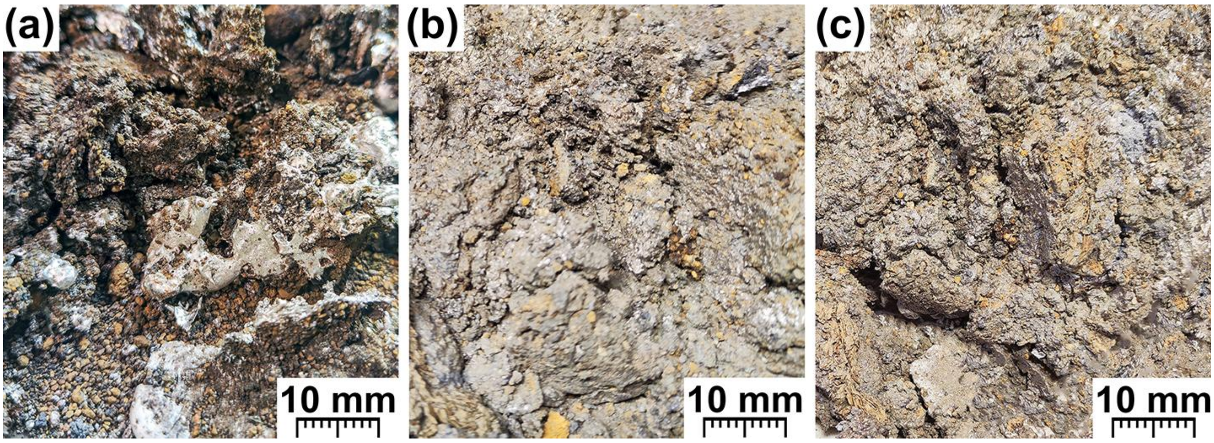

Fig. S-2. (a) Metallic dross obtained after the addition of aluminum. (b) Metallic dross obtained after adding calcium. (c) Metallic dross obtained after the addition of aluminum and calcium.

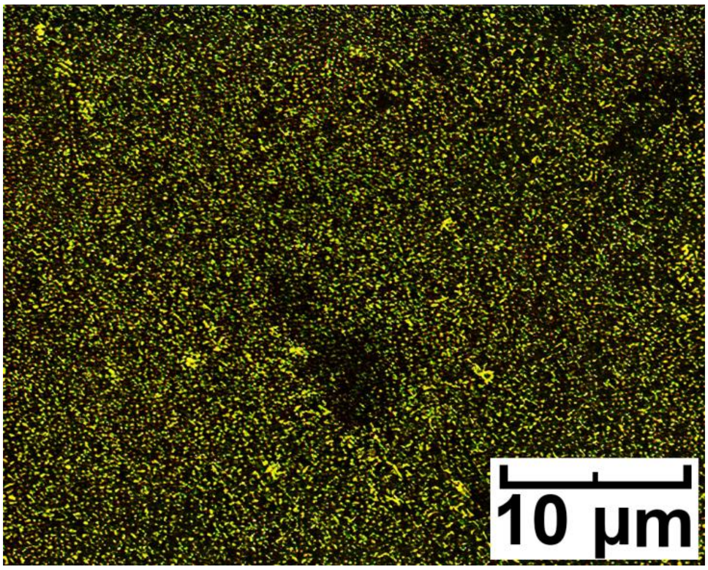

Fig. S-3. EDS mapping of Sn-containing areas for a sample of metallic dross after using Al-Ca mixture as a refining additive

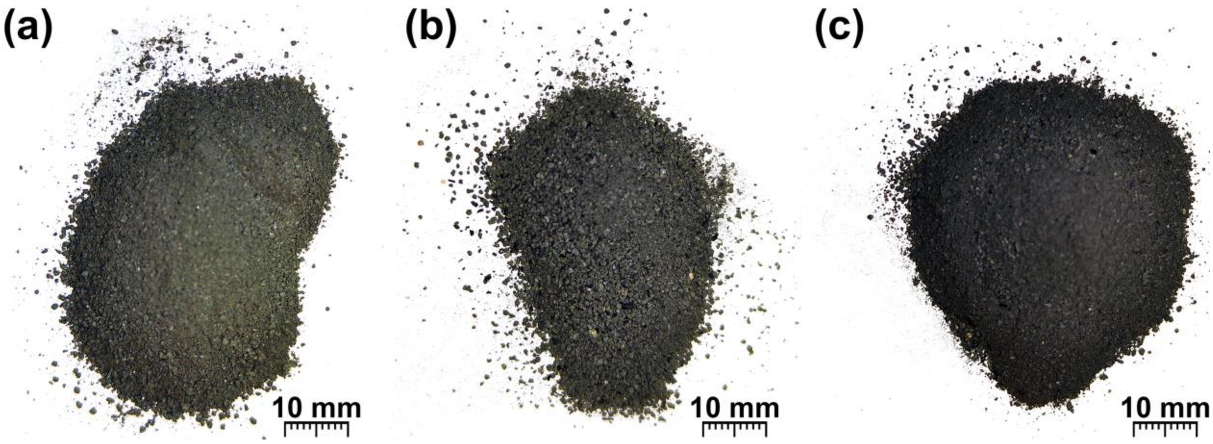

Fig. S-4. (a) Dross obtained after reduction of metallic dross containing aluminum. (b) Dross obtained after reduction of metallic dross containing calcium. (c) Dross obtained after reduction of metallic dross containing aluminum and calcium.

Table S-V. Elemental composition of metallic dross after adding aluminum in laboratory-scale tests (wt. %).

Element	Sn	Sb	As	Cu	Se
Content	1.0±0.1	3.5±0.4	3.2±0.3	1.6±0.2	0.9±0.05

Element	Ni	Te	Ca	Al
Content	0.15±0.05	0.16±0.05	0.0009±0.0001	0.9±0.4

Element	Bi	Ag	Pb
Content	0.015±0.003	0.0030±0.0004	76.6±1.6

Table S-VI. Elemental composition of metallic dross after adding calcium in laboratory-scale tests (wt. %).

Element	Sn	Sb	As	Cu	Se
Content	1.3±0.1	1.6±0.3	1.5±0.2	1.3±0.2	0.11±0.05

Element	Ni	Te	Ca	Al
Content	0.008±0.004	0.06±0.03	0.8±0.2	0.0009±0.0001

Element	Bi	Ag	Pb
Content	0.015±0.001	0.0032±0.0004	92.1±1.9

Table S-VII. Elemental composition of metallic dross after adding aluminum and calcium in laboratory-scale tests (wt. %).

Element	Sn	Sb	As	Cu	Se
Content	1.1±0.1	2.1±0.3	0.9±0.1	0.65±0.09	0.4±0.2

Element	Ni	Te	Ca	Al
Content	0.02±0.01	0.21±0.06	0.2±0.1	0.6±0.3

Element	Bi	Ag	Pb
Content	0.015±0.001	0.0030±0.0004	88.3±1.9

Table S-VIII. Element composition of dross obtained after reduction of metallic dross using Al as a refiner (wt. %).

Element	Pb	Sb	As	Cu	Se
Content	59.7±0.9	5.9±0.6	5.8±0.5	2.9±0.3	0.9±0.2

Element	Ni	Te	Sn	Al
Content	0.26±0.06	0.13±0.05	0.6±0.1	1.3±0.2

Table S-IX. Element composition of lead obtained after reduction of metallic dross using Al as a refiner (wt.%).

Element	Sn	Sb	As	Cu	Se
Content	1.42±0.04	0.52±0.03	0.011±0.002	0.04±0.01	0.012±0.002

Element	Ni	Te	Bi	Ag
Content	0.0018±0.0005	0.0026±0.0004	0.0152±0.0005	0.0033±0.0003

Element	Cd	Tl	Ca	Al
Content	0.0004±0.0001	0.0029±0.0001	0.00001±0.00003	0.0002±0.0001

Element	Pb
Content	97.958

Table S-X. Element composition of dross obtained after reduction of metallic dross using Ca as a refiner (wt. %).

Element	Pb	Sb	As	Cu	Se
Content	66.5±1.1	2.9±0.3	8.9±0.9	7.6±0.5	0.2±0.1

Element	Ni	Te	Sn	Ca
Content	0.03±0.01	0.06±0.02	0.5±0.1	0.9±0.3

Table S-XI. Element composition of lead obtained after reduction of metallic dross using Ca as a refiner (wt. %).

Element	Sn	Sb	As	Cu	Se
Content	1.47±0.04	1.30±0.03	0.13±0.04	0.09±0.02	0.09±0.01

Element	Ni	Te	Bi	Ag
Content	0.008±0.001	0.05±0.01	0.0153±0.0005	0.0047±0.0004

Element	Cd	Tl	Ca	Al
Content	0.0013±0.0002	0.0031±0.0001	0.0009±0.0002	0.00001±0.00001

Element	Pb
Content	96.830

Table S-XII. Dross obtained after reduction of metallic dross containing aluminum and calcium in laboratory-scale tests (wt. %).

Element	Pb	Sb	As	Cu	Se
Content	81.6±1.8	4.7±0.5	2.6±0.2	1.8±0.5	0.8±0.2

Element	Ni	Te	Sn	Al	Ca
Content	0.18±0.04	0.11±0.05	0.7±0.1	1.1±0.3	0.2±0.1

Table S-XIII. Element composition of lead obtained after reduction of metallic dross using Al and Ca as a refiner (wt. %).

Element	Sn	Sb	As	Cu	Se
Content	1.44±0.04	0.82±0.02	0.02±0.01	0.07±0.01	0.02±0.01

Element	Ni	Te	Bi	Ag
Content	0.003±0.001	0.005±0.001	0.0155±0.0005	0.0032±0.0003

Element	Cd	Tl	Ca	Al
Content	0.0006±0.0002	0.0030±0.0001	0.0007±0.00001	0.00008±0.00009

Element	Pb
Content	97.604

Supplementary references

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