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# Aluminum: Recycling and Environmental Footprint

DAVID S. WONG[1,3] and PASCAL LAVOIE[2]

1.—Light Metals Research Centre, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand. 2.—Aluminum Center of Excellence, Alcoa, Deschambault, QC, Canada. 3.—e-mail: david.wong@auckland.ac.nz

Since 2000, global primary aluminum production has increased by 250% to an annual output of almost 65 million metric tonnes in 2018, much of this due to growth in China.[1] Global demand continues to be driven by the need for strong, lightweight materials for vehicles and transport (to reduce fuel consumption and greenhouse gas emissions), durable and long-lasting materials for building and construction, protective packaging for food products, innovative consumer products, and many other uses.[2] Aluminum's durability and almost limitless recyclability, requiring only 5% of the original energy to produce primary metal, make it a key material and commodity in the world today.[2]

By 2040, global aluminum demand is projected to continue to grow, to as much as 90 million tonnes of primary metal per year with an additional 70 million tonnes of demand met by recycled aluminum.[3] However, it is clear that further intensification of global production must be sustainable and matched by effective solutions that can address both current and future environmental challenges faced by the industry. The following *JOM* topic brings together eight articles highlighting the latest research in aluminum recycling and in the mitigation of environmental impacts from primary aluminum production, particularly management of hazardous by-products and airborne emissions.

This *JOM* topic presents four articles on the management of bauxite residue (also known as "red mud"), a solid by-product from the Bayer alumina refining process and a major environmental challenge. With current global inventory estimated at 3 billion tonnes and over 150 million tonnes being generated each year,[3,4] much of it in long-term storage facilities, it is vital that the aluminum industry continues to develop effective, large-scale programs to remediate or reuse this by-product stream. The first article by Vaughan et al., titled "The Sandy Desilication Product Process Concept," proposes a novel approach to address the challenge of reactive silica impurities in bauxite. These precipitate in the Bayer process as desilication product (DSP) and are discarded with bauxite residue, resulting in losses for the alumina refinery and making bauxite residue management more complex. The authors examine coarsening of this DSP via controlled crystallization, which provides lower-cost extraction and recycling of aluminum and sodium in the DSP than conventional sinter-leach processes.

The second article, titled "Comprehensive Recovery of Iron and Aluminum from Ordinary Bayer Red Mud by Reductive Sintering–Magnetic Separation–Digesting Process," by Gao et al. presents a design of experiments to optimize sintering and alkaline digestion conditions (temperature, time, ratio of added $MgO/SiO_2$, and % NaOH) for their proposed RSMSD process, recovering up to 91% iron and 70% aluminum from bauxite residue. In this process, the magnetic separation step occurs prior to digestion, improving iron recovery, and MgO is used as the mineralising agent instead of the typical CaO. A third article, by Wang et al., titled "Assessment of Bauxite Residue for Reclamation Purposes, following Calcification–Carbonization Treatment," compares the soil characteristics of treated bauxite residue with those of natural soil, nutritional soil, and untreated bauxite residue, if using it for reclamation purposes. Similarly, the fourth article, by Shi et al., titled "Analysis of Remediating Effects of Peat, Sawdust, and Gypsum in Alkaline Bauxite Residue Based on Orthogonal Experiments," examines the suitability for plant growth of remediated bauxite residue following application of different treatments

Moving away from the Bayer process, Zhou et al. present research relating to the extraction of alumina from coal fly ash (a major industrial waste stream from the coal-fired energy sector in China) as an alternate input to the primary aluminum industry. Their paper, titled "Heating Mechanism of

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High-Aluminum Fly Ash Activated by $Na_2CO_3$ in Microwave Field," examines the activation of aluminum compounds in fly ash using microwave heating (as opposed to using conventional calcination) and the microwave absorption characteristics of fly ash and $Na_2CO_3$ mixtures, important parameters for further development of microwave processing.

Two additional articles examine the environmental impacts of aluminum reduction via the Hall–Héroult process. The first article is a review of raw off-gases and emissions from aluminum reduction cells by Aarhaug and Ratvik (SINTEF, Norway), titled "Aluminum Primary Production Off-Gas Composition and Emissions: An Overview." The article discusses typical industrial off-gas components (including $CO_x$, fluorides, $SO_x$, and particulates) and their interaction with impurities in raw material inputs to the smelter; the authors also provide a useful overview of analytical techniques for off-gas measurements.

Another article covers treatment of spent pot lining (SPL), the used lining materials from an aluminum reduction cell at the end of its service life, classified as hazardous waste due to the presence of cyanides. With up to 1.5 million tonnes of additional SPL being generated per year in the world,[3,4] a range of solutions is required as there is no single solution that is technically and economically feasible for all smelters. The article titled "Vacuum Distillation-Treated Spent Potlining as an Alternative Fuel for Metallurgical Furnaces" by Li et al. describes a vacuum distillation process to treat SPL (first-cut) to recover leachable fluorides, and to increase the carbon content and hence calorific value for potential use in metallurgical blast furnaces.

The final article in this *JOM* topic explores further potential pathways for aluminum recycling. In their article "Processing and Microstructural Characterization of Metallic Powders Produced from Chips of AA2024 Alloy," Rofman et al. (NUST MISiS, Russia) present the concept of recycling scrap aluminum alloy by mechanical milling (with stearic acid as a process control agent) rather than the conventional process of remelting. Optimum milling conditions were examined, producing fine aluminum powders, potentially for use in additive manufacturing, hot/cold compressing, or other applications.

The following papers being published under the topic of Aluminum: Recycling and Environmental Footprint provide excellent details and research on the subject. To download any of the papers, follow the URL http://link.springer.com/journal/11837/71/9/page/1 to the table of contents page for the September 2019 issue (vol. 71, no. 9).

- "The Sandy Desilication Product Process Concept" by James Vaughan, Hong Peng, Dilini Seneviratne, Harrison Hodge, William Hawker, Peter Hayes, and Warren Staker.
- "Comprehensive Recovery of Iron and Aluminum from Ordinary Bayer Red Mud by Reductive Sintering–Magnetic Separation–Digesting Process" by Feng Gao, Jihao Zhang, Xinjie Deng, Kaituo Wang, Chunlin He, Xinsheng Li, and Yuezhou Wei.
- "Assessment of Bauxite Residue for Reclamation Purposes After Calcification–Carbonization Treatment" by Yanxiu Wang, Ting-an Zhang, Guozhi Lv, and Weiguang Zhang.
- "Analysis of Remediating Effects of Peat, Sawdust, and Gypsum in Alkaline Bauxite Residue Based on the Orthogonal Experiment" by Ben Shi, Xue Liu, Huanhuan Deng, and Sujie Yang.
- "Heating Mechanism of High Aluminum Fly Ash Activated by $Na_2CO_3$ in Microwave Field" by Baocheng Zhou, Junwen Zhou, Libo Zhang, Tu Hu, Li Yang, and Guo Lin.
- "Aluminium Primary Production Off-Gas Composition and Emissions: An Overview" by Thor Anders Aarhaug and Arne Petter Ratvik.
- "Vacuum Distillation-Treated Spent Potlining as an Alternative Fuel for Metallurgical Furnaces" by Nan Li, Yan Jiang, Xiang Lv, Lei Gao, and Kinnor Chattopadhyay.
- "Processing and Microstructural Characterization of Metallic Powders Produced from Chips of AA2024 Alloy" by O.V. Rofman, A.S. Prosviryakov, A.V. Mikhaylovskaya, A.D. Kotov, A.I. Bazlov, and V.V. Cheverikin.

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