# POSTDOCTORATE OFFER IN MATERIALS SCIENCE

# Solid-state recycling of aluminum alloys, an innovative process for enhanced sustainability

### Employer description

The Institute of Research of Chemistry Paristech (IRCP) and the Institute of Chemistry and Materials Paris East (ICMPE) are two academic research laboratories of CNRS (French national scientific research center), in the field of materials science. Their multidisciplinary research activities are focused on materials for energy as well as sustainable processing. In this context, strategies to decrease the environmental impact of metallic alloys are studied.

### Background

To limit global warming, the European Union has committed to reduce its greenhouse gas (GHG) emissions by at least 40 % in 2030. To meet this ambitious goal, as any other sector, the one of metallic alloy production has to dramatically decrease its emissions. To do so, the development of new recycling methods is a promising approach. Currently, metallic alloys are recycled by re-melting. In this processing path, aluminum scraps (from machining of pieces or from end-of-life goods) are collected, sorted (if needed, mostly for end-of-life goods), refined during the refusion step (removal of impurities and adjustment of the composition for the end use), cast and processed. Due to the amount of impurities accumulating during recycling, coming from the melting in single batches of aluminum alloys with varying compositions, recycled alloys are mostly used in the cast channel, which is more tolerant to impurities. Therefore, high-value wrought aluminum alloys are often downgraded to the cast channel upon recycling (78% of the end-of-life aluminum scraps). Recycling aluminum alloys decreases very significantly the GHG emissions compared to the production from ores. Indeed, available figures from the literature indicate that between 168 and 200 GJ are required to produce one ton of primary aluminum, when the recycling by refusion consumes only 16 to 19 GJ, most of the energy is saved from avoiding the electrolysis extracting aluminum from alumina.

To decrease them even more, **a new "solid-state recycling" process considering the direct extrusion of the aluminum scrap, without going through the refusion stage, is proposed**. This approach requires only 5-6 GJ/ton. **On top of decreasing further the energy necessary for the recycling, this strategy decreases the number of processing steps in the fabrication chain** of aluminum goods, by possibly producing semi-finished products directly, **and avoid downgrading** by reprocessing wrought extruded alloys in the same channel. As such, it contributes to add value to the wrought aluminum alloys from the urban mines. It could finally cut down the transportation costs and GHG related to the transportation of aluminum in the various steps of its current recycling path.

### State of the art and objectives

The solid-state recycling process takes metallic chips as input. After compaction of the chips and a short homogenization treatment, hot extrusion is performed, directly producing new ingots. One drawback of the solid-state recycling approach is that it is impossible to remove impurities, contrary to the current recycling path, where the fusion step allows to adjust the composition, and to remove impurities such as oxygen.

To provide a proof-of-concept of the applicability of this technique, solid-state recycling was applied to an aluminum alloy, with chips produced by machining in the lab. As such, characterization of the material at the various steps of the process, namely master ingot, chips, annealed chips and extruded ingot was possible. The ingots were prepared by TU Dortmund, a partner of the project, that has developed this process and thus has a strong knowledge on the technique. The extruded ingots were characterized by the IRCP lab and the ICMPE lab.

The first results evidence that a dense material is produced. However, oxygen analyses at the different steps of the process surprisingly reveal an increasing content of oxygen in the material, as we move along the transformation path. More detailed analyses (electron probe micro analysis – EPMA, and scanning electron microscopy - energy dispersive X-ray spectroscopy – SEM-EDS) revealed the presence of a network of former chips boundaries in the material, enriched in oxygen (O) and magnesium (Mg). Mg being an alloying element, this shows an interaction between impurities coming from the process (as oxygen) and alloying elements (as magnesium), finally modifying the microstructure. Besides, Mg is added in the material for its structural hardening, in the form of Mg2Si precipitates. Mg consumption in the form of oxides could be a problem for the subsequent hardening treatment, always performed in this family of aluminum alloys.

**The objectives of the project are thus to study the precipitation of $Mg_2Si$ in the chips-based extruded material, to characterize the impact of Mg consumption during the oxidation on the hardening capacity. When necessary, new precipitation conditions will be proposed.**

### Methodology and missions

To answer the objectives of this project, chips-based extruded AA6060 alloy will be studied, and compared with the cast and extruded reference material. First, thermal treatment will be performed. Then, the precipitation will be studied first by differential scanning calorimetry and resistivity measurements, and characterized by micro-hardness.

Transmission electron microscopy (TEM) experiments will then be done, to access a detailed characterization of the precipitates (composition, density, size, spatial distribution). In-situ heating experiments in the TEM will allow to track the precipitation. If relevant, atom probe tomography will be performed in collaboration with GPM lab (Rouen).

Based on the results, possible modifications to the classical precipitation treatments will be proposed and implemented, to finally assess whether mechanical properties in hardened conditions are maintained after chips extrusion.

### Practical informations

The PhD will take place in the Institute of Research of Chemistry Paristech (Paris) and the Institute of Chemistry and Materials Paris East (Thiais), under the direction of Lola Lilensten (IRCP) and under the supervision of Mathilde Laurent-Brocq (ICMPE).

The project is done in collaboration with the TU Dortmund (Prof. Tekkaya), Germany. A PhD on the solid state recycling of aluminum started on the 1st of October 2022 and undergraduate students regularly join us. The postdoctorate will participate to all the projects meetings and interact with the other members of the project, especially the PhD student.

The postdoctorate will be funded by the DIM MaTerRe of the “Région Île de France”, for a duration of 12 months. It can start the soonest on the 1st of February 2023. The gross salary is comprised between 2850 and 3500€/month depending on the experience.

**Candidate profil**

Required:
PhD in metallurgy, with experience in experimental work.
Autonomy, rigor, initiative and efficiency.
Capacity to write scientific publication

Additional:
Experience in TEM analysis of precipitates and precipitation.
Knowledge in aluminum alloys

Application: please contact Mrs Lola Lilensten lola.lilensten@chimieparistech.psl.eu and Mrs Mathilde Laurent-Brocq Mathilde.laurent-brocq@cnrs.fr