ALUMINUM -- A LUNAR ENGINEERING MATERIAL

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Abstract

Metallic aluminum is a valuable engineering material in space, with many uses, e.g., as electrical conductor and structural material. Fortunately, aluminum is abundant on the lunar surface, occurring as the oxide, complexed with other metal oxides to minerals such as anorthite.

A concept to produce aluminum from lunar oxides is proposed. It involves separation of oxides at elevated temperatures in vacuum, then the electrolysis of aluminum oxide dissolved in a fluoride melt. Oxygen and calcium metal would be by-products of the process.

Uses for Aluminum

Aluminum is an engineering material with many uses in space, in lunar outposts as well as in solar power satellites.

Aluminum and aluminum alloys are excellent light-weight structural materials that can be shaped easily by casting, rolling, drawing, and welding. Aluminum can be sprayed, vapor deposited and atomized. Its low melting point of 660 °C provides advantages over the use of iron or steel.

Pure aluminum is an excellent conductor of electricity and heat. This property can be exploited to collect the power generated by the cells of solar power satellites, as well as more generally in electric cables and bus bars, and to dissipate heat originating from processing, power generation and other sources.

The surface of aluminum may be employed to reflect solar radiation, either to collect solar energy or to shield areas from excessive heating.

Aluminum used as solid propellant has a remarkable theoretical impulse. Producing aluminum powder on the Moon could reduce the requirement for terrestrial hydrogen [1].

In view of its potential of satisfying essential requirements and its versatility as engineering material, production of aluminum on the lunar surface appears attractive.

Lunar Aluminum Resources

Aluminum generally occurs in nature as the oxide, often complexed with other metals and particularly with silicon in silicate rocks. A practical source of aluminum on the Moon is the feldspar mineral plagioclase which is abundant in highland areas [2]. Anorthite, $CaSi_2Al_2O_8$, of good purity has actually been obtained from a lunar soil sample by magnetic separation [3]. Anorthite is particularly desirable as process feed material if silicon as well as aluminum is to be produced.

Targeting aluminum as the major product of interest, we suggest processing lunar oxides by vacuum treatment at elevated temperatures. Components such as iron, silicon and titanium oxide are expected to evaporate preferentially, leaving aluminum oxide and calcium oxide behind [4] [5]. The remaining calcium aluminate can then be used as a starting material for the extraction of aluminum metal. Anorthositic soil is again a desirable raw material, but other resources high in aluminum oxide content are also feasible.

Lunar Production of Aluminum

Aluminum oxide is a very stable compound, requiring considerable energy for the separation into its two components, aluminum and oxygen. Electrolysis provides the most effective means to accomplish this separation in terrestrial practice. It most likely will also be the best approach to produce aluminum from lunar resources.

EMEC Consultants developed a process concept to extract silicon and aluminum from lunar anorthite [6]. This process involves a step to electrolyze aluminum and calcium, following a non-electrolytic reduction of silicon. If silicon is not a desired product, the process can be simplified by the pretreatment of the ore before the electrolysis. The envisioned process is summarized by Figure 1.

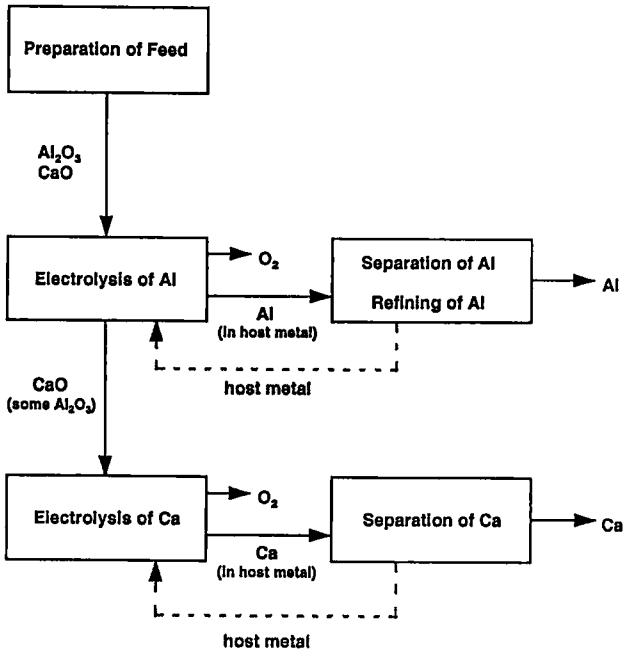

Figure 1. Process Concept to Produce Aluminum from Lunar Soil

The preparation of feed in the initial vacuum process step may be simple: heating the soil and evaporating the components that are more volatile than calcium oxide and aluminum oxide. Volatilization of oxides is being studied at EMEC Consultants [7].

The prepared feed, essentially calcium aluminate, is dissolved in a CaF_2-LiF molten salt electrolyte. In a first electrolysis step, aluminum is cathodically deposited into a host metal. It is periodically extracted from the host metal by vacuum treatment and refined to an extent commensurate with the application. In the second electrolysis step, calcium is reduced,along with some remaining aluminum and some lithium. The calcium is then recovered from this host cathode metal.

While aluminum is the product of primary interest, calcium is a by-product that may find application as electrical conductor. Oxygen evolved at the anode during electrolysis is another useful by-product.

A specific effort to develop the process concept described has not yet been made, but has been proposed to the Space Studies Institute for consideration. Results from other efforts, however, will be applicable. EMEC Consultants, with the support of NASA, is presently studying the separation of oxides by applying vacuum at elevated temperatures [7]. The electrolysis of oxides has been studied extensively by EMEC Consultants. Promising electrode materials and operating conditions for this electrolysis have been identified, but further work is required.

Synopsis

An attractive possibility of producing aluminum from lunar resources exists. The envisioned process involves several process steps which need to be developed. Results from ongoing efforts on related processes are directly applicable. Historically, the development of electrometallurgical and of other similar processes has required many years. It is advisable and probably most cost-effective to start now the development of a desired process.

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