In-situ Extraction of Al-Sc by Metallothermy via Vacuum Induction Melting

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Abstract

The extraction of metallic Sc from Sc-bearing compounds produced by prior processing steps in the value chain of red mud / titanium tailings treatment is the final stage of material conversion. Subsequently, the metallic product is prepared to be alloyed and used for high-tech applications, e.g. in aerospace. Hence, efficient and applicable extraction processes are sought. Metallothermic reduction of Sc compounds is investigated in the framework of the EU-funded project SCALE in order to identify potential processing routes that are scalable, efficient and target-oriented. Thermochemical calculations were the starting point to calculate systems of interest, as the parametrization of the process in its equilibrium state is the baseline for experimental validation. The self-propagation of the extraction was questioned, as the enthalpy balance of the calciothermic and aluminothermic ScF_3 reduction was determined at -1402 J/g and -346 J/g, respectively, which is far below conventional metallothermic reduction techniques. To provide the heat balance for the reduction, a vacuum induction furnace (VIM) is chosen as its atmosphere is adjustable and the energy input occurs directly through interaction of the system with the applied induction field. The following approaches were found to be most promising: For ScF_3, pure substances reduction with Ca was chosen as initial approach to extract Sc in pure metallic form. Simultaneous extraction of Al from Al_2O_3 and Sc from ScF_3 by Ca is an in-situ extraction of an Al-Sc master alloy with an all-liquid slag as by-product. Aluminothermic reduction of ScF_3 yields a high Sc-containing alloy with a gas phase / condensate as by-product. Additionally, fluorine-free alternatives were investigated, in which Sc_2O_3 is potentially reduced by Ca/Zn. In experimental examinations of the systems previously simulated, the aluminothermic reduction of ScF_3 and the co-reduction of Al_2O_3 and ScF_3 were identified as most promising approaches for further development. Pure substances approaches (calciothermic reduction) are thus not producible as the VIM technology does not provide sufficient retention times of the volatile reducing agents inside the system and an inhomogeneous product is extracted that only exhibit microscopic regions of Sc separation from F. However, VIM is suited exceptionally well for aluminothermic ScF_3 extraction due to the fact that the reactants are liquid/solid and the side product gaseous, while no liquid slag is

involved. Hence, ceramic crucibles may be applied that pose many advantages regarding their practicability, induction performance and costs. Also, a casting procedure is feasible, as well as the specific condensation of volatile by-products with technologies developed and applied in SCALE. The final metallic product exhibits Sc concentrations at 15 wt%, with minor contaminations of Mg and Y at 1000 ppm and 500 ppm, respectively. On the other hand, the co-reduction of Al_2O_3 *and* ScF_3 *is highly interesting from an academic point of view, because rate-controlling extraction steps are taking place that are subject to the research conducted. Also, thermochemical modeling does not provide sufficient insights as kinetic effects do not allow for an equilibrium state. Hence, for* Al_{met} *and* F_{slag}*, the values computed and experimentally investigated differ strongly (60.8 wt% and 20.8 wt%, respectively, as measured via ICP-OES). Nevertheless, the co-reduction also shows interesting features for an effective Al-Sc synthesis, as high metallic Sc-containing regions (up to 32.5 wt%) are found in the product.*

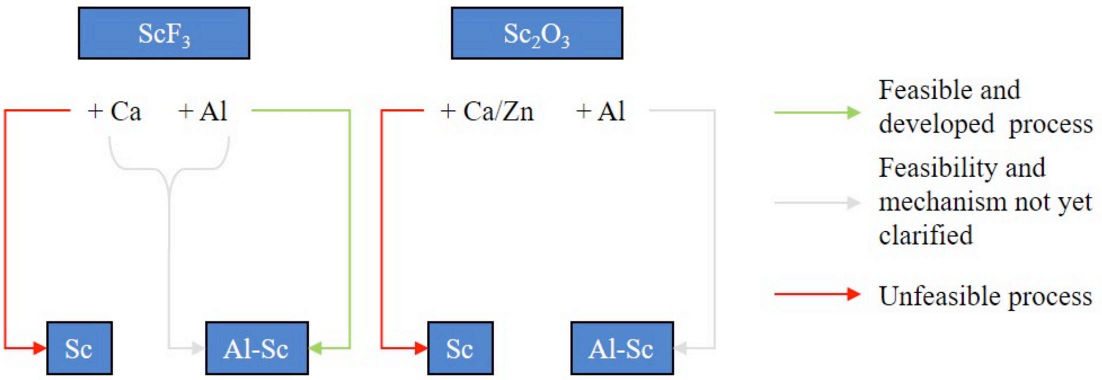

Figure 1: Extraction pathways investigated with feasibility indications