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The production of a pig iron and calcium aluminate slags for alumina recovery from bauxite ore.

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Abstract: Bauxite ore is the main raw material used to produce alumina, through the dominant industrial method called the Bayer Process. This method causes the generation of Bauxite Residue (BR) or red mud that creates environmental challenges. An alternative process with no BR production called the Pedersen Process was running in Norway for almost 50 years. This process is a combined pyro and hydro-metallurgical process in which the bauxite ore first is treated with lime and coke through a smelting reduction process. This yields a calcium aluminate slag with pig iron as a by-product. The slag is further hydrometallurgically treated to produce alumina. For recovering the alumina, the generated phases must be leachable, that is containing $12CaO.7Al_2O_3$, $3CaO.Al_2O_3$ or $CaO.Al_2O_3$. The pig iron byproduct can be further used in the ferrous industry and foundries. In this work, the smelting reduction of a Greek bauxite ore is studied by using coke and biocarbon. Moreover, the characteristics of the produced slag and pig iron are studied. The smelting reduction of bauxite shows that iron can be separated from the slag, in addition to a suitable slag formation for further alumina extraction.

Bauxite ore is the main raw material used for alumina production. Bauxite ore is composed primarily of alumina hydroxide minerals and other minerals consisting of iron, titanium, and silicon oxides [1]. The Bayer Process generates a non-consumable waste called Bauxite Residue (BR) or red mud to large amounts which contains almost all the iron of the ore and other impurities [2]. The alternative Pedersen Process was operated between 1928-1969 at Høyanger, Norway, with an annual production of 17 000 metric tons [3-4]. In the traditional Pedersen process, coke and lime are used in the smelting-reduction of bauxite in electric furnace and reviving this sustainable process for alumina production is the objective of the Ensureal EU project [3, 5-6]. The slag produced in the smelting reduction of bauxite should contain phases that are suitable for leaching and so recovery of alumina. The desirable phases in the process slag are $12CaO.7Al_2O_3$, $CaO.Al_2O_3$, $3CaO.Al_2O_3$ and $CaO.2Al_2O_3$ [7]. Therefore, proper amount and chemistry of flux should be added regarding the TiO_2 and SiO_2 oxides of the bauxite to form $CaO.TiO_2$ and $2CaO.SiO_2$, respectively to prevent undesirable phases in the slag [4, 7]. Hence, the characteristics of the slag play an essential role. It is worth noting that the pig iron byproduct can be further used in the ferrous industry and foundries and the solid residue of the leaching step can be used for other purposes [3,6].

RESEARCH AND METHODOLOGY

In the present study, the carbothermic reduction of a Greek Bauxite ore is studied in the lab-scale while experiments done in pilot-scale as well. The Bauxite ore used in this study contains 67.5% Al_2O_3, 24.32% Fe_2O_3, 2.87% SiO_2, 2% CaO, 3% TiO_2 in dry basis. In addition to bauxite, lime, coke, and charcoal with 95.5% CaO, 87.7% C-fix, and 79.4% C-fix, respectively, were used. The use of charcoal is to establish a more sustainable process with the use of less fossil fuels.

Mixtures of bauxite ore, lime, coke, and charcoal were prepared by mass balance calculations based on the measured chemical compositions of materials. The mass ratio of lime/bauxite was equal to 0.63 while the addition of the carbon materials based on their total fixed carbon, C-fix, content. The coke addition was 1.5 times more than the stoichiometric, to assure the complete iron reduction. The mixture I contains 100% Coke, while the mixture II contains both coke and charcoal in a 42%/57% analogy. The mixtures were melted by heating up to 1650ºC and holding for 1 hour at this temperature, in an induction furnace for the lab scale experiments. In Fig. 1a and b macroscopic observations of the produced slag are presented, and the Fig. 1 c presents the phase analysis of the slags.

The chemical analysis of the slags showed that the *mass ratio* of CaO/Al_2O_3 was in the desirable

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range. As an example, slag II contains 52% Al_2O_3, 49% CaO, 2.2% SiO_2, 2.4% TiO_2, and 0.3% Fe. The low content of iron (around 0.5%) indicates the reduction of iron oxides from the bauxite ore. Moreover, the phases formed in the highest part of the slag II, Fig. 1c, are considered more proper for hydrometallurgical treatment according to the literature [7-8]. The Penta-calcium tri-aluminate phase, ($Ca_5Al_6O_{14}$) formed in slag I and slag II in the lower part, is consider as an intermediate phase for Mayenite ($12CaO.7Al_2O_3$) formation [9]. The mixture II result in a better slag and metal separation, Fig. 1b.

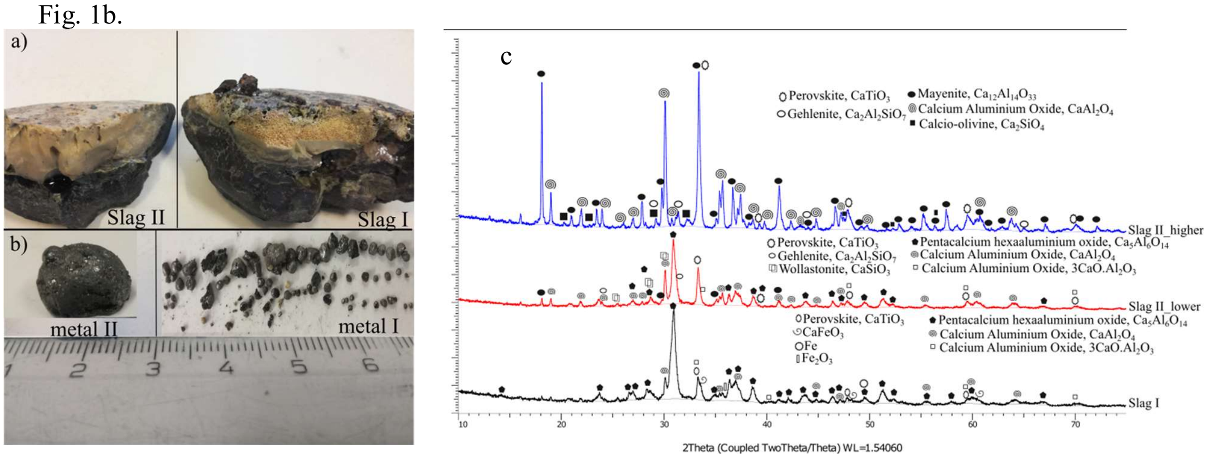

Fig. 1: a) macroscopically observations of slag I and II, b) metal II and I, c) XRD analysis of slag I, slag II.

Based on the obtained results in the batch type lab scale experiments, a semi-continuous smelting-reduction trial in pilot-scale was done using a 440kVA single phase electric arc furnace, at SINTEF lab. In this test several metal and slag tapping was done and the carbon type material change from metallurgical coke to charcoal was studied. The change from coke to charcoal caused a better burden and smelting characteristics, with no affect on power consumption.

The obtained results in both the lab and pilot scale trials show that separation of iron from bauxite and the formation of slags with leachable compounds from bauxite ore is feasible. The slag characteristics indicate that the slags are proper for the leaching step of the Pedersen process, if the slag chemistry is properly controlled.

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