PILOT SCALE STUDY ON THE USE OF BLENDED LATERITE AND IRON SAND AS FEED MATERIALS FOR SHAFT FURNACE IRONMAKING

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ABSTRACT: *This study investigates the feasibility of using blended low-grade laterite ore and iron sand concentrate as feed materials for pilot-scale shaft furnace iron making. Three (3) different blend ratios of % low-grade laterite to % iron sand concentrate were tested, namely 70:30, 50:50, and 30:70. Feed blending was adapted to complement the inherent properties of the ore and concentrate to produce pig iron that will only require minimal refining, and which can easily be used for commercial or industrial applications. Based on the results, the production of pig iron from the blended low-grade laterite ore and iron sand concentrate is feasible. From the three (3) feed blend ratios, the 30% low-grade laterite and 70% iron sand concentrate had the highest iron content in the pig iron, optimum smelting productivity, least non-metallic components in the pellets, lowest slag viscosity resulting to a continuous smelting process, and least extent of required refining process.*

Keywords: *Laterite, Iron Sand, Shaft Furnace, Iron making*

1. INTRODUCTION

Ironmaking is the production of metallic iron or pig iron from iron ores which then proceeds to refining and processing of cast iron and steel products. The blast furnace (BF) technology has been the dominating ironmaking process for the past centuries and still currently remains the prime route for the world's pig iron production, an intermediate material used in the production of commercial iron and steel. The BF is also considered as the most energy-efficient method for ore-based hot metal production [1].

Several chemical reactions occur in a blast furnace [2]. The coke (carbon) burns with oxygen to produce carbon dioxide (CO_2). This reaction is exothermic. The CO_2 then reacts with more coke producing carbon monoxide.

$$C + O_2 \longrightarrow CO_2$$
$$CO_2 + C \longrightarrow 2\,CO$$

Carbon monoxide acts as a reducing agent for the iron ore and reacts with the iron oxides to produce molten iron and carbon dioxide gas [3]. The molten iron flows to the bottom of the furnace where it is then collected.

$$3\,Fe_2O_3 + CO \longrightarrow 3\,Fe_3O_4 + CO_2$$
$$Fe_3O_4 + CO \longrightarrow 3\,FeO + CO_2$$
$$FeO + CO \longrightarrow Fe + CO_2$$

The limestone in the furnace decomposes, forming calcium oxide. This is a fluxing agent which combines with impurities to form slag, which floats on top of the molten iron.

$$CaO + SiO_2 \longrightarrow CaSiO_3$$

The typical feed used in blast furnaces is hematite iron ores which may be in the form of lump ores, sinters, or pellets [4]. In the Philippines, the most common iron sources are iron sand and nickeliferous laterite ores.

Iron sand, locally known as black sand, naturally occurs in black sand beaches in the Philippines which results from the weathering and erosion of metamorphic and igneous rocks [5]. It is the most applicable iron ore deposit in the country for ironmaking. However, prior concentration by magnetic separation is required before being suitable for smelting reduction or direct reduction process. Laterite, on the other hand, is a surface formation deposit found in tropical countries that is enriched in nickel, iron, and aluminum and develops by intensive and long-lasting weathering of the underlying parent rock [6]. In the Philippines, direct shipping of raw laterite ores to other countries is the current dominant practice of nickel mining companies. Value-addition of these ores has been the constant motivation of the MGB to conduct research projects, such as this study.

Low-grade nickel laterites were investigated for pig iron production in the MGB study *Pilot-Scale Production of Nickel Pig Iron from Low-Grade Laterite Ores* [7] and concluded its feasibility. However, one of the recommendations is the careful selection of the ore feed quality which accordingly must have low alumina, sulfur, and phosphorus contents to eliminate problems such as high slag viscosity and the requirement of intensive refining, among others.

Hence, this study utilized blended low-grade nickel laterite and iron sand concentrate at different feed blend ratios to complement their inherent properties and produce pig iron, using a vertical shaft furnace, that will only require minimal refining and which can easily be used for commercial or industrial applications.

2. MATERIALS AND METHODS

2.1 Materials

Iron sand concentrates utilized in the study were gathered from the Philippine provinces of Cagayan, Bulacan, and Zambales. Low-grade laterite ores, on the other hand, were also obtained from Zambales. Both samples were initially subjected to drying for moisture removal. The laterite ores were pulverized using a high-speed hammer mill to obtain less than 50 mesh size (< 0.297mm).

Powdered carbon, bentonite, and calcium hydroxide were used as fluxes during pelletizing and served as reducing and binding agents.

Charcoal, limestone, and foundry coke were also used during reduction and smelting in the shaft furnace. Charcoal was used as a reductant (source of reducing agent). Limestone was added as a flux to remove impurities such as silica and alumina, among others. Foundry coke provided the necessary heat for the smelting process aided by the supply of hot air.

2.2 Experimental Procedures

Pelletizing

The pellets composed of a mixture of laterite ore and iron sand concentrate, powdered carbon, bentonite, and calcium hydroxide, at 1:6:2:0.5 or 1:6:4:0.5 proportions, were prepared using a drum pelletizer. Three (3) different blend ratios of laterite to iron sand concentrate were utilized, namely 70:30, 50:50, and 30:70. The formed pellets with a size of about ½-inch diameter were charged into a Liquified Petroleum Gas-heated oven for further moisture removal and hardening.

Smelting

Smelting was conducted in a shaft vertical furnace which simulates that of a blast furnace. It was initially pre-heated using charcoal and hot air (pre-heated air) for approximately 2.25 – 3.5 hours. Charcoal was first fed into the furnace stack while fire was lit at the tap hole opening aided by forced air using a small blower. To hasten the heating of the furnace, pre-heated air was also injected using a bigger blower. Metallurgical coke was then fed into the furnace to form a coke bed making the furnace even hotter. After pre-heating, a bucket containing the feed materials composed of successive layers of pellets, charcoal, limestone, and foundry coke was hoisted up and charged into the shaft furnace opening. A single bucket charge was composed of 125 kilograms of pellets, 60 kilograms of charcoal, 15 kilograms of limestone, and 15 kilograms of foundry coke. A total of 10 buckets were charged per smelting run in the shaft furnace. The smelting temperature was maintained at the range of 1500 - 1700 ^{0}C.

The material charges were smelted for almost an hour. Furnace personnel determine if the charged materials were already smelted by checking the level of the charge inside the furnace. This was done by manually inserting a steel rod inside the furnace to measure the level of the charge. Once the desired level was attained, the taphole of the shaft furnace was opened by removing the clay that covered the tap hole opening. Removal of the clay was done by oxygen lancing and allowing the flow of the molten pig iron and slag, which were then collected/poured into separate molds.

2.3 Analytical Method

The raw laterite ores and iron sand concentrates were analyzed using Shimadzu AA-7000 Flame Atomic Absorption Spectrometry (F-AAS) for iron and nickel, a gravimetric method for silica, and a titration method for alumina. The pig iron products were analyzed using the Hitachi Foundry-Master Optimum Spark Optical Emission Spectroscopy (OES). The slags were analyzed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) for scandium and Shimadzu 7000 Energy Dispersive X-ray fluorescence for the other elements/compounds.

3. RESULTS AND DISCUSSION

3.1 Characterization of Feed

Results of X-ray diffraction Analysis using Malvern Panalytical X'pert Pro MPD show that the laterite ores mainly consisted of goethite (FeO(OH)) and the iron sand concentrates of magnetite (Fe_3O_4) and ilmenite ($(Fe, Ti)_2O_3$). Such supports the high iron content results of the chemical analysis of both samples, as presented in Table 1.

Table 1. Chemical Components of Laterite Ores and Iron Sand Concentrates

	Fe, %	Ni, %	Al_2O_3, %	SiO_2, %	Cr_2O_3, %
Laterite 1	42.00	0.56	12.76	6.90	1.24
Laterite 2	52.01	0.66	2.99	1.78	5.59
Iron Sand 1	57.35		2.94	2.94	
Iron Sand 2	52.86		0.92	0.92	
Iron Sand 3	68.64		1.56	1.56	

3.2 Smelting

The blending of laterite and iron sand concentrate was adapted to complement the inherent properties of the ore and concentrate and produce pig iron that will only require minimal refining.

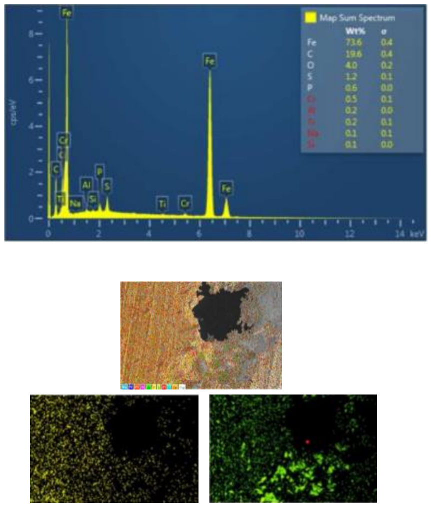
Analyses of the pig iron and slag products produced from the three (3) blend ratios of laterite and iron sand concentrate are shown in Tables 2 and 3, respectively.

Table 2. Spark OES Analysis of Pig Iron

Element, %	Blend Ratio (% Laterite: % Iron Sand Concentrate)		
	70:30	**50:50**	**30:70**
Fe	89.35	90.25	92.75
C	4.18	2.87	2.49
Ni	0.76	0.59	0.35
Cr	2.51	0.54	1.09
Si	0.18	0.90	0.18
Mn	0.75	0.22	0.14
Co	0.14	0.11	0.06
S	0.34	0.22	0.34
P	0.70	0.57	0.36
V	0.15	0.16	0.19

Based on the analysis of the pig iron products, the feed blend composed of 30% laterite and 70% iron sand concentrate had the highest iron content, as expected. However, the percent composition of most of the other elements (C, Cr, S, P, V) signifies the necessity of a refining process to be able to proceed with the casting and produce commercial or industrial products.

The sulfur and phosphorus concentrations of the pig iron must also be seriously considered during refining since they are way much higher than what is required for casting (~0.06% max S and ~0.1% max P). The presence of S and P were also confirmed in the Field Emission Scanning Electron Microscope (FE-SEM) analyses of the pig iron samples using the Dual Beam Helios Nanolab 600i of the Advanced Device and Materials Testing Laboratory (ADMATEL). Fig 1 shows the FE-SEM result of the 70% laterite to 30% iron sand concentrate blend ratio.



(a) (b)

Figure: EDS Spectrum and Elemental Color Maps showing the occurrences of (a) S and (b) P

Table 3. Analysis of Slag

Element	Blend Ratio (% Laterite: % Iron Sand Concentrate)		
	70:30	50:50	30:70
Fe, %	3.70	3.45	8.35
SiO_2, %	29.23	22.98	22.58
Al_2O_3, %	32.17	32.16	37.27
Cr_2O_3, %	2.08	0.94	0.93
TiO_2, %	4.51	5.28	3.53
Sc, ppm	9**1**	64	30
V_2O_5, %	0.18	-	0.19

The analysis of the slag products, on the other hand, shows a significant amount of scandium which can be investigated further for possible extraction/recovery.

Further observations during the conduct of pelletizing and smelting of the three (3) feed blends include: (1) the higher the percentage of iron sand concentrate in the feed, the higher the smelting productivity. Less slag volume was attributed to fewer non-metallic components of the pellets; (2) high iron sand concentrate in the feed blend caused difficulties in pelletizing. Efficient grinding and a higher quantity of bentonite were required to effectively bind and form the pellets; (3) a lesser percentage of laterite in the feed corresponds to a less viscous slag leading to a smoother and undisruptive smelting process. High slag viscosity was due to the presence of high Cr_2O_3 [8, 9, 10] and alumina [11] in the laterite.

4. CONCLUSION

The use of blended low-grade laterite and iron sand concentrate as feed materials for the production of pig iron is technically feasible. However, further refining of the pig iron products must be undertaken to meet the required composition by the foundries. From the investigated three (3) feed blend ratios of laterite and iron sand concentrate, the 30% low-grade laterite and 70% iron sand concentrate had the highest smelting productivity, least non-metallic components in the pellets, lowest slag viscosity resulting in a continuous smelting process, and least extent of the required refining process. A significant amount of scandium was also found in the slag and provides the feasibility of its recovery as a by-product of pig iron production.

Commercial implementation of the study can lessen reliance on imported raw materials for steelmaking, increase value-added processing of local minerals, diversify sources of iron, and promote a robust mine-to-metal value chain.

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