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Full Length Research Paper

Use potentials of Delta Steel Company (DSC), Ovwian-Aladja, western Niger Delta, Steelmaking Slag in Agriculture

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Abstract

Delta Steel Company steelmaking slag (DSC slag) samples produced by the direct reduction steelmaking process using direct reduced iron (DRI), scrap and lime (flux material) as ingots were collected at the company dump site, Ovwian-Aladja. This research work was carried out to determine the possible use of DSC slag in agriculture to realize the current benefits in agriculture of steelmaking slag production through recycling. Fifteen bulk samples were subjected to X-ray fluorescence (XRF) Geochemical analysis to determine their potential uses in agriculture. The results showed the presence of important agriculture element oxide concentrations by weight per cent of CaO(36.62%), Fe_2O_3(27.32%), SiO_2(19.86%), MgO(9.77%), Al_2O_3(5.43%), MnO(1.46%), K_2O(0.05%) and P_2O5(0.57%). Free lime (0.06%), was detected by Titrimetry. The slag had high basicity ranging between pH8.2 and pH9.5 which can improve soil pH can be a plant nutrient and stabilizer for soil aggregates. Increase of pH of agricultural soil can also lead to a decrease in Al solubility which allows phosphorus (P) absorption due to the changing of insoluble forms to soluble ones. The application of the slag can increase K, Ca and Mg in soils. Because of its Ca and P contents, the basic slag can be used as a fertilizer and as a liming material. Natural agricultural resources being used in the company environment would be conserved and also, the sale of slag for use in agriculture can generate revenue for economic development. This can also promote the Nigerian steel industry sustainability with particular reference to the iron and steelmaking companies at Ovwian-Aladja and Ajaokuta.

Keywords: DSC slag, X-ray fluorescence analysis, geochemical analysis, agriculture, fertilizer, improved crop yield.

Introduction

Delta Steel Company (DSC) steel plant in Nigeria, is situated at Latitude $5^0$28' North and Longitude 5^0 47' East between Ovwian (East) and Aladja (West) giving the composite name of Ovwian-Aladja to the company. The area falls within the rainforest belt of the Niger Delta, experiences mean maximum rainfalls of 340mm during the period of rainy season (April – October), and 77mm during the dry season (November – March). However, maximum rainfalls of 33mm in 15 minutes are known to have been recorded. These rainfall figures account for abundance of ground water supply to the plant and the area through boreholes. Mean annual maximum temperatures of 31^0C along with a mean minimum of 23^0C have been recorded in the area. The rainfall and temperature in the whole area in the western Niger Delta have created conducive conditions for agricultural purposes for the 300,000 people.

The steel plant is an integrated one and the process of steel production is based on the direct reduction technology using reformed natural gas for the direct reduction of pelletized iron, followed by electric furnace arc melting and continuous casting. The total plant area approximates to 1,080,000 square meters (1200m x 900m) for the first 1.0 million tons (Mt) of steel production. The slag dump along the road on the Aladja side has 207,000 square meters (900m x 230m) approximately.

Since inception in 1985, to the time of investigation, DSC produced 1,176,939 tonnes of slag out of which only a small volume of 144,657.72 tonnes (12.29%) had been put to uninvestigated use on company site as aggregate. This low utilization of the slag may probably have arisen as a result of lack of technical knowhow about the various uses into which the slag could be put, particularly in the area of agriculture.

The bulky slag samples collected had characteristic sizes ranging between about 5.30cm x 3.00cm x 2.90cm to about 31.70cm x 22.30cm x 19.65cm of very irregular shapes with vesicular upper surfaces and almost flat basal surfaces with whitish infillings of tiny netlike fractures probably due to more rapid cooling contraction on contact between hot slag and cooler dump slag surface assisted by water sprayed to assist in cooling. The vesicular upper surface in the slag is attributable to escape of volatiles from the free upper surface. The general colour observed of the slag varied from dark grey (vesicular) to bluish grey (non-vesicular), and some samples had thin coatings of brownish white to whitish coloured powder which easily rubbed off. The coating could be due to weathering or lime hydration. All the samples had very irregular and sharp edges and had high densities judged by hand, some having entrapped metallic steel, iron or minor entrapped refractory impurities.

Slags are the main by-products generated during iron and crude steel production classified as BF (Blast Furnace) slag or steelmaking slag (Branca and Cola, 2012; Takahashi and Yabuta, 2002). The steel industry is committed to increasing and improving their recycling as steel production has increased over the past decades. The reuse of the higher volumes of these materials in an increasingly efficient way has become mandatory, necessitating and resulting in the expansion of new technologies in recent years. This improved the recovery rates of slags for use in industry including, agriculture. The increased recovery rates allowed reduction of landfill slags, preservation of natural resources and produced economic benefits, by providing sustainable solutions that can allow the steel industry to achieve its ambitious target of “zero-waste” in the incoming years (worldsteel, 2008). Steelmaking slag is produced by two main ways. The iron ore based steelmaking slag production way using iron ore, coal, limestone and recycled steel scrap represents about 60-70% of the world steel production.

The iron making iron ore based on Blast Furnace (BF) followed by steelmaking in the Basic Oxygen Furnace (BOF), and the iron making based on Direct Reduction of Iron ore (DRI), followed by steelmaking in the Electric Arc Furnace (EAF), is the main production routes. Delta Steel Company follows the latter route of slag production using lime from limestone. Ironmaking and steelmaking slags which are the main by- products of iron making and steelmaking that represent 90% of the total by-products, dusts and sludges (Branca and Cola, 2012). On the average about 200 kg of byproducts per ton of steel result from the steel production through electric arc furnace, while about 400 kg of by-products per ton of steel production through BF/BOF. The use of by-products from steel industry goes back to many centuries ago. Geiseler, (1996), reported that the use of steelmaking slag, as phosphating and/liming agent started in 1880.Slags being dumped are now considered marketable products and only a small percentage is processed as industrial waste in landfills.

At Delta Steel Company (DSC), the main steel making slag production ingots are direct reduced iron from Liberian iron ore and locally sourced scrap iron at a ratio of eighty (80) per cent to twenty (20) per cent respectively. This was to ensure purchase of scrap at local markets without difficulties and to alleviate the problems associated with DR processes having higher DRE charging with hot heel. Scrap used included steel scrap devoid of non-ferrous materials, excessive corrosion, oil/greeze and dirt, in accordance with ISIS 203 for heavy melting steel scrap II. The lime used as fluxing material was produced from high quality Mfamosing limestone, Calabar. Three hundred and three thousand, nine hundred and fifteen, and ninety seven (303,915.97) tones of slag produced as at the time of this research out of an expected 1,435,604.80 tonnes was mainly dumped away at the Aladja side dump site. On estimation, the fraction of below capacity slag produced sold for use as aggregate at the company site at the rate of Three Naira (₦3.0) per tonne, generated ₦853.68 per day, ₦5,975.76 per week and ₦274.884 per annum. More can be generated when more tonnes are produced and sold for other uses, particularly agriculture, the purpose of this research.

This work therefore determined the use potentials of DSC slag as fertilizer in agriculture rather than being dumped away to realize the current benefits in agriculture of steelmaking slag production through recycling. The use potentials of the slag based on the geochemistry, include liming agent, fertilizer to improve soil pH, as plant nutrient, improvement of fertility of acid soils, increase phosphate mobility, providing plant resistance to biotic and abiotic stresses diseases. Natural resources being used in agriculture in the environment would be conserved and the sale of the slag/slag fertilizer should generate revenue for economic development. This can promote the Nigerian steel industry sustainability with particular reference to the iron and steelmaking companies at Ovwian-Aladja and Ajaokuta.

Materials and Methods

Materials: Fifteen steelmaking slag samples were collected by random spot hand picking from Company (DSC) slag dump, for laboratory testing according to British Standard BS812 (part 3), 1975, 1988) specifications. Each of the spot samples was labeled and put into a transparent bag which was also labeled, with an indelible ink. The bulk size samples were taken to the laboratory for suitable test sample preparation.

Test sample preparation and test equipment: A rock cutting machine, jaw crusher and a fly press were used to produce suitable test samples. The fly press produced gravel and sand size grades which were ground to powder samples in a Tema mill at switch 1 at a time of 30 seconds (1 x 30 seconds). The powder was then melted with Johnson Matthey spectroflux 105 and quenched to produce quenched glass discs for X-ray fluorescence geochemical analyses using the Phillips PW1212 XRF machine set with a Chromium tube operating at 60kv and 26mA conditions.

Results and Discussion

Results

Table 1presents the mineralogy of the slag by Titrymetry and the X-ray fluorescence (XRF) analyses results are presented in Tables 2 and 3 below.

Table 1: Mineralogy of DSC slag selected samples by Titimery

	SAMPLES							
	N7	N8	N9	N13	N17	N19	Mean	SD
Freelime %	0,05	0.06	0.06	0.06	-	-	0.06	0.01

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Table 2: Bulk Geochemistry of DSC Slag in weight per cent (%) by X-ray fluorescence analyses (XRF)

Oxide Composition %	Samples									
	N7	N8	N9	N10	N12	N13	N14	N17	N19	N21
S_IO_2	2.42	21.64	19.74	19.52	19.20	19.27	19.72	20.19	18.18	18.25
T_IO_2	0.42	0.46	0.42	0.39	0.40	0.41	0.45	0.44	0.42	0.41
Al_2O_3	5.16	5.92	5.95	5.25	4.59	5.42	5.00	5.50	5.63	5.55
Fe_2O_3	17.93	21.70	26.33	28.20	27.69	25.50	25.22	26.71	25.97	25.73
Cr_2O_3	0.05	0.10	0.00	0.00	0.06	0.04	0.06	0.01	0.40	0.40
MnO	1.67	1.33	2.03	1.03	1.82	1.53	1.46	1.18	1.23	1.26
MgO	7.94	9.65	10.95	9.00	7.41	9.68	8.02	7.52	12.37	12.54
CaO	44.20	39.57	35.50	37.96	38.96	37.92	38.25	39.88	36.40	35.82
Na_20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.03	0.06	0.05	0.08	0.04	0.08	0.04	0.03	0.02	0.03
P_20_5	0.62	0.51	0.53	0.60	0.77	0.57	0.56	0.46	0.39	0.60
SO_3	0.06	0.14	0.10	0.08	0.03	0.00	0.04	0.02	0.00	0.00

Table 3: Mean, minimum and maximum geochemistry of DSC slag in weight per cent (%) by X-ray fluorescence analysis (XRF)

Field	Mean	Std. dev	Min	Max
SiO_2	19.861	1.331	18.180	22.420
Al_2O_3	5.426	0.374	4.590	6.000
Fe_20_3	27.323	5.402	17.930	41.000
Cr_20_3	0.168	0.184	0.000	0.450
MnO	1,456	0.296	1.030	2.030
MgO	9.766	2.171	7.050	13.430
CaO	36.623	4.227	27.230	44.200
Na_2O	0.00	0.00	0.00	0.00
K_2O	0.05	0.018	0.02	0.08
P_20_5	0.565	0.078	0.440	0.770
$S0_3$	0.039	0.043	0.000	0.140
TiO_2	0.423	0.022	0.390	0.460

Results on Table1 showed the presence of free lime, Tables 2 and 3 indicated that the main compounds of DSC slag were calcium, silicon, magnesium, aluminium and iron oxides, CaO(36.62%), Fe_2O_3(27.32%), SiO_2(19.86%), MgO(9.77%), and Al_2O_3(5.43%) respectively. There were no noticeable organic substances possibly due to the high temperatures (1500^0C) of operation. The slag protected the metal bath from oxygen and maintained temperatures through a kind of lid formation. The slag floated because it was lighter than the liquid metal. X-ray diffraction studies showed that the major phases present in the slag were silicates (dicalcium, merwinite and melilite), calcium alluminate and wustite, (Wessey, 1988; www.intechopen.com 340), but also contained the reactive free CaO and MgO. The dicalcium silicate polymorph, belite, ($2CaO.SiO_2$) is also reactive (Wessey, 1988; Das, et al., 2007).These mineral phases were the major sources of the DSC slag major components particularly, CaO, Fe_2O_3, SiO_2 and MgO which made it suitable for soil conditioning and subsoil strengthening (Abbaspour and Sharinmadan, 2005)). The effective contributory parts DSC slagCaO, MgO, Fe_2O_3, P_2O_5, $SiO_{2,}$ and basicity would play in slag use in agriculture, are briefly discussed below.

CaO and MgO

The high levels of lime (CaO) and MgOin particular, made the slag a potential liming agent, may improve or increase soil pH and can be used as plant nutrients (Ali and Shahram, 2007). Free lime (CaO), present can be separated and be used as fertilizer and in soil conditioning. The free lime present as a minor constituent (Table 1, can partially dissolve by reacting with water to produce calcium hydroxide, $Ca(OH)_2$, as shown in the equation:
$CaO + H_2O \rightarrow Ca(OH)_2$. The calcium hydroxide dissolves into Ca^{2+} and OH^- and this can result in a pH increase. MgO can also behave same way as CaO undergoing the same actions. $MgO + H_2O \rightarrow Mg(OH)_2$. It is also possible that the Ca and Mg soil contents can increase, resulting in an increased plant yield, while the consequence of increased pH is reduction in toxic effects of Mn (MnO(1.45%) (Table 2) (Babula, et. al., 2008). All these factors characterizing DSC slag, indicated that it can improve the fertility of acid soils (Besga et al., 1996; Shamim et al., 2008; Jamali, et al., 2006).

Fe_2O_3

The iron content of DSC slag is high (27.32%) (Table 2). By this content, the slag has potential for use as iron fertilizer for corn growth popular around Delta Steel Company and environments of Ovwian and Aladja and for soil improvement. The application of the slag as fertilizer with or without sulphuric acid can increase the dry yield of some crops particularly sorghum (Anderson and Parkpin, 1984) but when the slag is used as a fertilizer through a mixture of sulphuric acid and iron sulphates, it can allow the correction of Fe chlorosis in corn to prevent yield loss (Stroehlin and Berger, 1963). The moderate use of DSC slag as Fe fertilizer can lead to Fe increase in Fe uptake (Wang and Cai, 2006) or make it available (Torkashvand, 2011).

P (P_2O_5)

Phosphorus is a known essential element for plants and animals. It is also used for fertilizer production along with nitrogen (N) and potassium (K). In steelmaking, phosphorus which originates from iron ore has a detrimental effect on steel. It is removed from the hot metal through the steelmaking slag. The mean contents of P(P_2O_5 (0.57%)) ranging between 0.44% and 0.77% and K (K_2O- 0.05%) ranging between 0.02% and 0.08% were detected in DSC slag. Though the contents are too low for the slag used as phosphate fertilizer, they cannot be ignored. The P and can be used to provide some phosphorus and potassium for plants, as the slag has some sorption capacity for phosphorus, deduced from its water absorption, ranging between 0.04% – 0.14% and porosity, between 2.19- 2.38% (Wessey, 1988). This made the slag suitable also for use in agriculture. The phosphorus can remain in the soil in a form available for the plants (Branca, et al., 2009). The phosphorus can be regenerated in the slag to increase its content within the steelmaking process through recycling making it suitable as fertilizer (Li et al., 1995, Dippenaar, 2004)).

Silicate (SiO_2)

SiO_2 (silicate) content in the slag is high, a mean of 19.86% ranging between 18.18% and 22.42%. The silicate has a special bond in the minerals, useful for plant nutrition and soil quality, and has a potential as siliceous liming material that should improve soil structure and reduce fungal infections. The silicate can provide beneficial effects on plant health and soil structure, increase the phosphate mobility in the soil and increase the efficiency of phosphate fertilization (Rex, 2002). The slag along with some other elements that were not considered essential, under particular agro-climatic tropical conditions, can increase crop yields by promoting some physiological processes. The application of slag made Si fertilizer can have beneficial effects on both rice and sugarcane increased yield in the Ovwian-Aladja and Effurun environments because possible Si accumulation protects plants from certain diseases, such as a resistance to biotic and abiotic stresses (Savant et al., 1999; Pereira et al. (2004), and can help plants against pathogen attacks (Motz and Geiseler, 2001; Takahashi, 2002). The use of DSC slag silica (SiO_2) as a fertilizer for rice can increase its resistance to diseases and vermin. The potential increase in sugarcane yield in the area may be associated with the alleviation of the toxicity of Al, Mn and Fe constituents of the slag, increased pH availability, reduced lodging, improved leaf and stalk erectness, freeze resistance and improvement in plant water economy (Branca and Colla, 2012). DSC slag can be produced in a hot metal desiliconization process, which contains mainly silica, to develop potassium silicate fertilizer despite the fact that the slag has a high concentration of silica (19.86%) and some potash (0.05%). This fertilizer, developed by adding potassium to the desiliconization slag, dissolves with difficulty in the water and slowly dissolves in the weak citric acid released by plant roots (Takahashi, 2002). Such a fertilizer can be as effective as other commercial potassium silicate fertilizers and combined potassium chloride-calcium silicate fertilizers when applied to rice and some vegetables, rice in particular. Silica (Si) in the soil available for plant when DSC slag is used as fertilizer can reduce the uptake of As (Bodgan and Schenk, 2009).

DSC slag effect as a basic slag

As a basic slag, it can be efficient in soil neutralization (Shamim et. al., (2008). It had high basicity ranging between pH8.2 and pH9.5 (Wessey, 1988), arising from high calcium and magnesium contents. The high basicity of the slag can improve soil pH due to its neutralizing effect which can release basic elements in acid sulphate soils, and the slag be a plant nutrient and stabilizer for soil aggregates. It can be treated physically to influence the solubility and plant availability of the nutrients. Increase of pH of agricultural soil can also lead to a decrease in Al solubility which allows phosphorus (P) absorption due to the changing of insoluble forms to soluble ones. The application of DSC slag can increase K, Ca and Mg in soils. Because of its Ca and P content, basic DSC slag can be used as a fertilizer, as it can improve the physico-chemical properties of the soil and increase plant growth; used as a liming material, as it can increase the precipitation and sorption of metals such as Cu (Rodriguez et al. (1994); Kühn et al., (2006); Negim et al., 2010).

A fertile soil which is one of the foundations of an increased crop growth, provides structure, minerals, and a balance of living organisms and decaying organic matter to plant roots. The soil must be nutrient rich and filled with living organisms (Carolyn, 2017). The Delta Steel Company area experiences high amount of rainfalls of about 340mm during the rainy season (April- October). This and the geology of the slag production environment, sometimes result in the leaching of these nutrients leading to the depletion of soil minerals and loss of topsoil faster than they can be replaced. Pesticides and synthetic fertilizers which have widespread use can also, imbalance the soil composition, causing rapid loss of nutrient-rich top soil. Monocultures practices and crops planting in the same place for multiple seasons can also cause mineral loss. This can leave plants vulnerable to disease and pests. Leeching of nutrients can cause the soil to effectively “die,” and make food crops more and more dependent on fertilizers.

Some of the missing nutrients in depleted soils include nitrogen, calcium, manganese and carbon known as macronutrients, rich in heavily fertilized soils but very poor in microorganisms and trace elements. Nitrogen which leeches easily from the soil and needs to be consistently, replenished, must be in a certain form in order for plant roots to use it. Though it is commercially added to the soil with ever-increasing amounts of fertilizer, nitrogen can remain available throughout all growing seasons through crop rotation, using compost, and other soil management techniques. Calcium, which levels are dropping rapidly, plays an important role in a plant’s structure and growth. It is usually returned to the soil through weathered rocks and decaying matter, but modern agriculture, erosion, and acid rain deplete it. Manganese is vital for photosynthesis and other processes. It can become depleted or unavailable to plants when soils are too wet, too high in organic matter, or too high in other elements, such as iron such as those of the slag production environment. Carbon is a critical element for the survival of living microbes. It is used and returned to the soil through organic matter. The loss of as many as these minerals makes soils likely to become more acidic which can in turn exacerbate the problem, as many plants are unable to properly absorb vital nutrients in acidic soils. Checking the pH levels is an important starting point to understanding the soil’s composition.

DSC slag, though has no detected carbon and nitrogen, had high contents of Calcium (36.623%), necessary for the plant structure and growth, Manganese (1.456%), vital for photosynthesis and other processes, a high concentrations of other agriculture important elements (Mg, Fe, P and Si), (Tables 1 and 2), and a high pH(8.2 – 9.5), good for neutralizing effect on an acidic environment for soil replenishment effecting beneficial increased plant growth and productivity. The slag can be suitable for use in agriculture.

Possible negative effects of DSC slag use as fertilizer

Heavy metals such as chromium and Vanadium are known to be broadly distributed in the Earth’s crust. Some of their chemical forms can be a potential risk to the biosphere, in particular to the water life because of their solubility while some are insoluble and often interact with soil particles and therefore, not available to plants (Babula, et al., 2008). The Chromium content in DSC slag (0.17%) (Table 2) is low, under oxidizing conditions (CR(III) to Cr(IV)) can be highly soluble and insoluble under reducing conditions (CrIV) to Cr(III). Both are stable in the environment.Cr^{3+} and $CrO4^{2-}$ are both available to plant roots absorption though Cr(III) which forms stable compounds for example, hydroxides, oxides and sulphates can be less soluble and, consequently less bioavalable (Srivastava et al., 1994). Based on chromium presence DSC slag can be used as a fertilizer. The possible negative effects that can result from DSC slag use in agriculture because of the presence of or possible presence of heavy metals, is negligible as such metals tend to bound to the slag matrix and therefore, not available for plants uptake. These factors have contributed to underline positive effects of using the test slag as liming materials, that can lead to better yield of the crops, soil protection and reduction of natural resources consumption (Hiltunen and Hiltunen, 2004); (Negim et al., 2010).

Conclusion

Nigerian steelmaking slag produced at the Delta Steel Company (DSC) is by the direct reduction steelmaking process using direct reduced iron (DR) and local scrap in the ration of 80% and 20% respectively. The fluxing material, lime (CaO) is obtained from Mfamosing limestone. The slag which forms the major by-product of DSC steel production is a basic one highly rich in CaO, SiO_2, Fe_2O_3, MgO. Other elemental oxide compositions include K_2O and P_2O_5 in noticeable amounts. All these are essential agriculture materials. DSC slag therefore qualifies to be used as a fertilizer, soil conditioner and as liming agent in agriculture to improve crop yield. The Company can generate revenue at the rate of three Naira (₦3.0) per tone or more ₦853.68 per day, ₦5,975.76 per week and ₦274.884 per annum or more from sales to construction and agriculture.

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