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Evaluation of the Characteristic and Content Development of Delta Steel Slag for Ground Granulated Slag Cement Production

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Abstract: The iron and steel industry is a great source of slag as a bye-product which could constitute a waste and pollutant to the environment. Due to this growing environmental protection need, iron and steel slag in Nigeria need to be properly recycled to enhance resource-conservation and energy-saving effects. The objective of this study is to determine the characteristic and suitability of Delta steel slag with content development in optimum blending proportion for the production of Ground granulated slag cement. This involves the experimental determination of the physical and chemical characteristics of DSC slag and analysis of the slag by comparison with set standards for Portland blast furnace cement. From these processes appropriate methods of manufacture has been proposed for the Ground Granulated Slag Cement.

Keywords: Slag, Granulated, cement, DSC, characteristic. Nigeria

1. Introduction

The iron and steel industry is faced with a wide range of environmental issues that that has direct bearing with the high energy consumption, material usage, and handling of the byproducts associated with manufacturing of about 794.8 million tonnes of steel per year worldwide [1]. The metallurgical processes that are carried out in this industry give rise to a number of bye-products, some of these include slag, blast furnace gas, coke oven gas, pellet fine, dust, flue gas, etc. In the advance economies the slag produced from the iron and steel industry after processing is used extensively in the production of blast furnace cement, as aggregates in the construction industries, the construction of roads as a highway base, railroad ballast, slag wool insulation and asphalt mixes. Thus, due to growing environmental protection need, iron and steel slag is recycled to enhance resource-conservation and energy-saving effects [2].

Blast furnace and steel slag are the products obtained in the manufacture of iron and steel in the blast and steel furnaces respectively. While the iron making process is a reduction process that of steel involves the oxidation of impurities to form slag.

Slag is a non-metallic bye-product resulting from the interaction of flux and impurities in the smelting and refining of metals. The global increase in the demand for iron and steel for industrial consumption resulted to a corresponding increase in the output of slag from the smelting process with the essential need for the recycling of the product.

The composition of the slag can vary over a wide range depending on the nature of the ore, the composition of the limestone flux and the kind of metal being made. These variations affect the relative content of the four major constituents, namely: lime, silica, iron and alumina [2].

Portland blast furnace is a mixture of Portland cement and granulated slag which constitute about 65% of the mixture according to BS 146:1958 [3]. Portland blast furnace cement is similar in physical properties to ordinary Portland cement, and the British Standard for the two is the same. It is manufactured from granulated slag. These involves chilling the slag very rapidly either by pouring into large excess of water or by subjecting the slag stream to jets of water or of air and water. The purpose is to cool the slag rapidly that crystallization is prevented and it solidifies as a glass. At the same time quenching breaks up the material into smaller particles varying from glassing bench to light weight froth. Generally, the production of a sound granulated slag is most easily achieved by quenching with high pressure jets which leaves the slag with lowest practicable water contents. Use of by-products such as slag from the production of iron and steel as cement materials leads to the conservation and optimal use of natural resources [4]. The use of slag material as a concrete constituent shows prospective application in construction industry as an alternative to conventional materials and solves environmental problems relating to waste disposal [5]. Upgrading of slag is effected by the removal of the iron content which is undesirable for cement production by the use of high intensity magnetic separation.

A review of related research efforts is presented as follows, reference [6] reviewed the efforts made in overcoming the challenges associated with the production of steel at Delta Steel plant, with Itakpe ore with excessive gangue content, to improve the quality of local iron ore and meet the needs of the Nigerian steel market. Test were carried out to determine suitable parameters and optimum conditions for its use in the iron making pelletizing and direct reduction plants and also the steel making plant. The paper concluded that the use of local beneficiated ore will lead to higher capacity utilization, further reduce cost of production and availability of steel products in the local market. Reference [4]studied alternative source for good quality concrete aggregates by investigating the physical, mechanical, and durability properties of concrete made with EAF oxidizing slag in addition to supplementary cementing material fly. The basic findings established that that EAF oxidizing slag and fly ash could be effectively applied as coarse aggregate material alternative and cement replacement in concrete applications. Reference [7], investigated the mineralogical and morphological characteristics of BOF and electric-arc-furnace-ladle [EAF(L)] slag samples by X-Ray Diffraction (XRD) analyses and Scanning Electron Microscopy (SEM). The paper recommended that the volumetric instability of the tested steel slag needs to be assessed for their use in civil engineering applications because of the presence of free MgO and CaO. Reference [8], investigated the influence of Steel Basic Oxygen Slag and Portland cement on the compressive strength and the hydration mechanisms of blended Grounded Granulated Blast Furnace Slag (GGBS) pastes. It established that steel slag can be used as an activator of GGBS and worked out the optimum composition of the materials with a slag index parameter. Reference [9], carried out a comparative analysis of the hydration characteristics of cement pastes incorporating steel slag or ground granulated blastfurnace slag (GGBS) as substitutes for ordinary Portland cement (OPC). The study established that cement with Electric Arc-Furnace steel slag content exhibits slow hydration rates in early stages which is however facilitated at later stages to exceed that of ordinary Portland cement mixtures. Reference [5], investigated the effects of replacing sand by high percentages of basic-oxygen furnace slag on the compressive strength, bulk density and gamma ray radiation shielding properties of concrete. It was observed that the strength of mortars increased significantly with the replacement of sand partially by iron slag. It was also observed that the inclusion of iron slag as partial replacement with fine aggregate enhances the bulk density of mortar

In Nigeria the Delta Steel Complex had produce slag in large enough quantity. But its later low capacity utilization resulted in reduced volume of main and bye-products. This also reduced the incentive to research on effective ways of exploiting the latent potentials of the slag. DSC also only produced air cooled slag that does not posses cementious properties. With these problems the only use DSC slag was put was in the filling of roads and swamping areas with very little research content.

Considering the facts that the Federal Government of Nigeria has put in place concrete measures to revive the moribund iron and steel sector with the associated resurgence of DSC slag in large quantity, there is the dire need to study the characteristic of the Nigeria steel slag to evolve an effective process for its processing and content development in optimum blending proportion to produce Ground Granulated Slag Cement (GGSC).

Portland blast furnace cement has the potentials to bring about positive changes in the Nigeria construction industry and economy. Its use as a supplement to the costly and insufficient Portland cement will assist considerably in bringing down the cost of housing construction.

The objective of this study is to carry out an assessment of DSC slag to study its characteristic and suitability with content development in optimum blending proportion for the production of Ground Granulated Slag Cement.

2. Steel and Blast Furnace Slag

Blast furnace slag is a bye-product obtained in the manufacture of Pig Iron in the blast furnace and is formed by the combination of the earthly constituents of the iron ore with the limestone flux. It consist of silicate and allumino silicates of lime and other bases, which developed in a molten condition [3]

Some analyses of blast furnace slag are given in Table 1 below. In general the lime may vary from 30 – 50%, silica 28 – 38%, alumina 8 – 24%, magnesia 1 – 18%, sulphur 1 – 2.8% and ferrous and magnesium oxide 1 – 3%. [3]

Table 1: Analysis of Blast Furnace Slag

Source	**Type**	**C_aO**	**SO_2**	**Al_2O_3**	**MgO**	**Fe_2O_3**	**MnO**	**S**
Britain	Basic	37 – 42	30 – 36	12 – 22	3 – 11	0.3 – 2.1	0.4 – 2.2	0.9 – 1.9
	Foundry	39 – 42	30 – 38	15 – 23	3 – 8	0.1 – 1.00	0.2 – 0.7	1.4 – 1.5
	Haemelite	38 – 47	32 – 37	10 – 22	3 – 9	0.4 – 1.30	0.3 – 1.00	1.1 – 1.4
Germany	Haemelite	40 – 44	34 – 25	11 – 13	6 – 8	0.3 – 0.4	0.5 – 1.1	1.4 – 1.8
France	Haemelite	40 – 48	29 – 36	13 – 19	2 – 8	0.5 – 3.80	0.1 – 1.0	0.4 – 9.5
USA	Haemelite	36 – 35	33 – 42	10 – 16	3 – 12	0.3 – 2.00	0.2 – 1.5	0.3 – 4.5

Steel slag is a bye-product of the refining of iron for the making of steel in the electric furnaces. The main difference between steel slag and blast furnace slag is that the former has a higher density and chemical make-up. The difference in chemical composition is mainly due to the presence of phosphate in steel slag while it is rare in blast furnace slag.

3. Constitution and Properties of Slag for Cement Production

Ordinary air cooled slag has no or very little cementious properties. Granulated slag alone has similarly negligible cementing action [10], but if some suitable activator is present, all except the rare siliceous granulated slag shows marled cementious properties. The activator may be lime, Portland cement, alkali such as caustic soda or sodium carbonate or sulphate of the alkali, lime or magnesia.

In general, the more basic the slag the greater its hydraulic activity in the presence of alkaline activities [11], with sulphate activators, the basicity of the slag is not only a criterion, the slag needs also to contain at least an average or moderately high alumina content. The glass content is a prime factor and an increase in the temperature of the molten slag when granulated promotes the hydraulicity of the product. It has been observed from experimental evidence that there is a linear relationship between strength and glass content.

Again the hydraulic value increase with the CaO and S_1O_2 ratio up to a limiting point when increase CaO content makes granulation to a glass difficult. The most favourable composition for the glass is 50% CaO, 31 S_IO_2 and 19% Al_2O_3.[3] A similar composition also provided the most favourable activations with 15% anhydrite and 2% Portland cement clinker corresponding to a supersulphated cement [3]. The optimal glass composition for Portland cement clinker activation was 51.5% CaO, 33% S_IO_2 and 15.5% Al_2O_3. For anhydrite activation the optimum composition in solution that the iron dissolved from slag can rapidly form strength producing hydrates phases. But the activator must also open the silicate structure of the glass so as to accelerate the rate of formation of an impermeable alumina silicate film which progressively combines with the slag. In case of sulphate activator, the initial attack will be on the alumina to form calcium sulpho aluminate and this must open up the silicate structure [3].

4. Test for Granulated Slag

When powdered granulated slag is examined on a microscopic slide by transmitted light, the glass is seen to consist of clear isotropic transparent grains. Less perfectly granulated slags may show brown or black zones where incipient crystallization has begun or even birefringent areas under crossed nicols [3].

The above two processes are used to estimate the effectiveness of the granulation process for slag to be used for cement production. The test is carried out each time granulated slag is to be used for cement production.

The above two processes are used to estimate the effectiveness of the granulation process for slag to be used for cement production. The test is carried out each time granulated slag is processed for cement production.

5. The Portland Blast Furnace Cement

Portland blast furnace cement is a mixture of Portland cement and granulated slag not more than 65% granulated slag according to BS146:1958. In U.S.A. where the cement is called Portland blast furnace cement, the granulated slag content is from 25 - 65% (ASTM595-68) [3]. The Portland cement is manufactured as usual or may be made from slag and limestone and burnt in the rotary kiln. The resulting clinker is then fed together with the required proportion or dry granulated slag and gypsum added to control the set.

Though, it has been usual to grind the Portland cement clinker and the slag together, they may be separately ground and subsequently mixed. When grind together, it is the softer material which will be preferentially ground and this is usually the clinker. With slag content up to about 50-60% the early strength is mainly influenced by the fineness of the clinker, there seem to be little difference in strength development between interground or separately ground material. Portland blast furnace cement is similar in physical properties to ordinary Portland cement and the British Standard for the two is identical in respect of finesses, setting time and soundness. The strength required is somewhat lower than for Portland cement as shown in Table 2.

Table 2: Strength Requirement of Blast Furnace and Ordinary Portland Cement

Mortar cubes (W/C 40%	**3 days** (kg/cm^2)	**7 days** (kg/cm^2)	**28 days** (kg/cm^2)
Blast furnace cement	112	210	351
Portland cement	122	154	210

It is generally recognized that the rate of hardening of Portland Blastfurnace cement in mortar or concrete is lower than that of Portland cement during the first 28 days but thereafter increase so that at 12 months the strength becomes close to or even exceed those of Portland cement [3].

Portland blast furnace cement is rather lighter in colour than Portland cement and has a slightly lower average specific gravity about 3.0 - 3.05 as compared with 3.1 - 3.15 for Portland cement. Gypsum act as a retarder while chlorides act as accelerating agents and may also increase the initial rate of hardening.

Other differences include; Portland blast furnace cement are more affected by low temperatures during the curing period and by inadequate curing than is normal cement. They are particularly useful for mass concrete structures because they have a somewhat reduced heat of hydration.

Portland blast cement concrete is more resistant to chemical attack, especially in sea water than ordinary Portland cement."

In blast furnace cement, variation in the MgO content up to about 8 - 10% may have little influence on strength development but higher content have an adverse effect. The German Standard requires that the slag shall conform to the format;

$$\frac{CaO + MgO + Al_2}{SiO_2} > 1 \qquad (1)$$

The SO_3 content of the cement is limited to 3.5% with specific surface 4000cm^2/g. The cement clinker use in the manufacture of Portland blast furnace cement is required to conform to the same composition limits as are laid down for Portland cement. Finished cement which may not contain more than 65% slag is required to conform to the following maximum values shown in Table 3.

Table 3: Composition of Portland blast furnace cement Clinker

	Material	Maximum values
1	Insoluble residue	1.5
2	Magnesia	7.0
3	SO3	3.0
4	Loss on Ignition	3.0
5	Specific surface	31.50cm^2/g
6	Expansion	2.0%

German blast furnace cement composition is shown compared with ordinary Portland cement.

Table 4: Comparative content of German blast furnace cement with ordinary Portland cement

Ordinary Portland Cement	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Mn_2O_3	SO_3
	61-68	19-24	3-7.0	0.7-3	1.5-7.2	0.0-0.2	1.3-3.0
Blastfurnace Cement	56-61	22-26	7-8	1.7- 4.0	1.3 - 3.3	0.1-0.5	2-3.0

6. Slag for the Manufacture of Portland Cement Clinker

The use of slag in place of shale or clay as a raw material for Portland cement manufacture yields ordinary Portland cement [12]. The method of manufacture is similar to that use when clay or shale is the raw material. The fuel consumption somewhat reduced by the use of slag limestone mix, since a smaller amount of calcium carbonate has to be dissociated during the burning. Both air cooled and granulated slag can be used [3]

6. Materials and Methods

6.1 Chemical Analysis of Slag

Test were carried out on steel slag from Delta Steel Complex (DSC) at Ukpilla Cement Factory, Ukpilla, Edo State. The titrametric method was used to determine the percentage composition of the slag.
The results of the tests is given below:

Table 5: Composition of Delta Steel Complex Slag

Slag	% Composition (Vol)
SiO_2	29.10
CaO	37.20
MgO	6.70
Fe_2O_3	15.40
TiO_2	0.10
Al_2O_3	9.30
U.D	2.20
	100

6.2 Standard Requirement of Slag for Cement Production

The Standard organization of Nigeria (SON) has set minimum standard for raw material for blastfurnace production. This standard, termed NIS 15:1980, is given below.

Table 6: NIS15:1980

Materials /Specification	**% Requirement**
Loss on Ignition	Max 3.0
Insolable Residue	Max 1.5
Magnesia (MgO)	Max 7
Sulphuric Anhydride (SO_3)	Max 3.5
Sulphide sulphur (S)	Max 1.5
*(CaO-0.7(SO_3)	Min 0.66
2.8 (S_1O) + 1.2 ($A1_2O_3$) + 0.65 (Fe_2O_3)	Max 1.02
$\frac{A1_2O_3}{Fe_2O_3}$	Min 0.66

The Chemical composition of the Portland cement clinker portion of the mixture shall comply where applicable with the requirement of NIS11:1979 (Ordinary Portland Cement).

6.3 Comparison of Slag Composition to Standard Requirement
6.3.1 Delta Steel Complex Slag

i. Silica, Alumina and Iron Relationship

The NIS15:1980 specification is;

$$2.8(SiO_2) + 1.2\,(A1_2O_3) < 1.02 \qquad (2)$$

In the composition of the slag
Silica oxida (SiO_2) = 29. 1%
Alumina ($A1_2O_3$) = 9.3%
Iron (ii) oxide (Fe_2O) = 15.4
Substituting in the relation

$$2.8(0.291) + 1.2\,(0.093) + 0.65\,(0.154)$$

$$0.8148+0.1116+0.1001 = 1.0265$$
$$= 1.03$$

This shows a variation of (1.03-1.02) = 0.01, which is negligible.
This variation is obviously due to the high content of Iron (11) oxide which is 15.4%. A look at BS.5146.1958 gives a clearer picture of the maximum composition of iron (11) oxide in blastfurnace slag for cement production.

Table 7: BS146:1958

Mat	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	MnO	S
% comp	38-42	32-37	10-22	3-9	0.4-1.3	0.5-1.1	1.4-1.8

Comparison with international slag production shows that the iron content should be in the region of 3-5% maximum. However, the main effect of iron (11) oxide is to impart a characteristic dark colouration on the cement. To avoid the above effect, steel slag for cement production are usually subjected to the process of electromagnetic separation. In the dry process about 75% of the iron content is liberated from the slag.
For the DSC slag, which contains 15.4% after being subjected to the separation process will contain.

15.4 - 0.75 x 15 = 15.4 - 11.55 = 3.85%
FeO_3 = 3.85% which is within tolerable limit.

ii. Alumina-Iron Oxide Modula Ratio

$$\frac{Al_2O}{Fe_2O_3} = 0.66 \quad (3)$$

$$Al_2O_3 = 9.3\%$$
$$Fe_2O_3 = 15.4\%$$

Substituting gives, $\frac{9.4}{15.4} = 0.604$

This shows a variation of 0.66 - 0.604 = 0.056 which is negligible. However, after the treatment of the slag, the result becomes:

$$\frac{9.3}{3.85} = 2.42$$

iii. Calcium Oxide, Sulphur Trioxide Relationship

CaO – 0.7 (SO_3)
The So_3 content of the slag is nil. Since this relationship is to check the So_3 content, attention was now focused on the CaO composition. A look at the international slag production composition for the production of cement show it is above the minimum requirement of 30%.

iv. Sulphuric Anhydride and Sulphide Sulphur
The NIS15:1980 specify for sulphuric anhydride and sulphide sulphur a maximum of 3.5% and 1.5% respectively. These materials are absent in the steel slag. The above materials are contaminants with adverse effects on cement.

v. Magnesia
For magnesia the slag composition is 6.7% and the NIS15:1980 specify a maximum of 7.0% thus, the content is in order.

vi. Loss on Ignition
Loss on Ignition for steel slag was 0.0% while NIS15:1980 specify a maximum of 3.0%.

7. Evaluation of Local Portland Blastfurnace Cement Composition of DSC Slag

The NIS15:1980 specify that, "Portland Blastfurnace Cement shall be an intimate and uniform blend of Portland cement clinker and granulated slag, produced either by intergrinding Portland cement clinker, granulated blastfurnace slag, and gypsum as required or by blending Portland cement and finely ground granulated slag.
Portland Blastfurnace Cement shall contain not less than 20% and not more than 65% by weight of finely ground granulated blast furnace slag.
According to the NIS15: 1980, 'The chemical composition of the Portland cement clinker portion of the mixture shall comply where applicable with requirement of NISII:1979 (Ordinary Portland cement)"

Table 8: NISII:1979 (Ordinary Portland cement)

Materials /Specification	% Requirement
Silica (SiO_2)	19-24%
Insoluble Residue (IR)	1.5%
Alumina (Al_2O_3	4.9%
Ferric Oxide (Fe_2O_3)	1.6-6%
Lime (CaO)	60-67%
Magnesia (MgO)	4.0%
Sulphuric Anhydride (SO_3)	3.0%
Loss on Ignition (L.O.I)	4.0%

The Portland cement clinker of Ukpilla Cement Factory, Ukpilla was used in blending the slag. A typical Portland Cement Clinker in Ukpilla Cement Factory has the following composition:

Table 9: Portland Cement Clinker Composition

Materials /Specification	% Requirement
SiO_2	21.6%
I.R	0.8%
CaO	64.5%
SO_3	1.3%
Fe_2O_3	3.2%
Al_2O_3	5.0%
MgO	3.6%

6.4 Blending Process

Blending of Portland Cement Clinker and slag was carried out using the relationship shown below. It gives the percentage composition of GGSC materials from the percentage composition of the slag and Portland cement clinker.

$$\frac{A(B)+(1-A)C}{100} \tag{4}$$

Where,
- A = Blending ratio in percentage for slag
- B = Percentage composition of the material in slag
- C = Percentage composition of the material in Portland cement clinker.

In the blending 50kg slag was blended with 50kg Portland cement clinker in various blending proportion to produce 50kg GGSC.

Table 9: 20% Slag & 80% Clinker, 4% Gypsum

Material	Slag	Clinker	20% Slag (Kg)	80% Clinker (Kg)	Composition by mass of Slag cement (Kg)	% Composition.
SiO_2	29.1	26.1	2.91	8.64	11.55	23.1
CaO	37.20	64.5	3.72	25.8	29.52	59.04
MgO	6.7	3.63.2	0.67	1.44	2.11	4.22
Fe_2O_3	15.4	-	1.54	1.28	2.82	5.64
T_1O_2	0.10	5.0	0.01	-	0.01	0.02
Al_2O_3	9.3	-	0.93	2	2.93	5.86
U.D	2.20	0.8	0.22	-	0.22	0.44
I.R		1.3	-	0.32	0.32	0.64
SO_3			-	0.52	0.52	1.04
	100	100	10	40	50	100

Table 10: Slag 65 & 35% Clinker, 4% Gypsum

Material	Slag	Clinker	20% Slag (Kg)	80% Clinker (Kg)	Composition by mass of Slag cement (Kg)	% Composition
SiO_2	29.1	26.1	9.46	3.78	13.24	26.48
CaO	37.20	64.5	12.09	11.29	23.28	46.76
MgO	6.7	3.6	2.18	0.63	2.81	5.62
Fe_2O_3	15.4	3.2	5.01	0.56	5.57	11.14
T_1O_2	0.10	-	0.03	-	0.03	0.06
Al_2O_3	9.3	5.0	3.02	0.875	3.895	7.79
U.D	2.20	-	0.72	-	0.72	1.44
I.R		0.8	-	0.14	0.14	0.28
SO_3		1.3	-	0.23	0.23	0.46
	100	100	32.50	17.50	50	100

Table 11: 40% slag & 60% Clinker, 4% gypsum

Material	Slag	Clinker	20% Slag (Kg)	80% Clinker (Kg)	Composition by mass Slag cement (Kg)	% Composition.
SiO_2	29.1	21.6	5.82	6.48	12.5	24.6
CaO	37.20	64.5	7.44	19.35	26.79	53.58
MgO	6.7	3.6	1.34	1.08	2.47	4.84
Fe_2O_3	15.4	3.2	3.08	0.96	4.07	8.08
T_1O_2	0.10	-	0.02	-	0.02	0.04
Al_2O_3	9.3	5.0	1.86	1.5	3.36	6.72
L.O.I	0.0	-	-	-	-	-
U.D	2.20	-	0.44	-	0.44	0.88
I.R	-	0.8	-	0.24	0.24	0.48
SO_3	-	1.3	-	0.39	0.39	0.78
Total	100	100	20	30	50	100

8. Discussion of Results

This study involves the assessment of slag from Nigeria Iron and Steel Industry as a raw material for the production of Ground Granulated Slag Cement. Chemical analysis of the slag and comparison with the Nigeria Industrial Standard (NIS) of the standard Organization of Nigeria (SON) reveals that Slag from DSC contains a high content of Iron (II) Oxide which imparts a characteristic dark colouration to the cement hence to enhance its quality, a beneficiation process of magnetic separation is required.

A maximum blending proportion of 65% and a minimum of 20% slag to Portland cement clinker were used to evaluate the composition of the GGSC using results of the chemical analysis and it shall contain such when manufactured.

The major limitations are that DSC does not produce granulated slag; hence a granulating tank and process should be instituted in the DSC production chain for the purpose of granulation of the slag. Also the high iron content imparts a dark colour to the GGSC which can easily be removed by grinding and magnetic separation.

The attempt to solve the problem of high cost of cement and housing in Nigeria has so far remained intractable. According to reference [13], due to inherent industry challenges, local cement production has stagnated at 50% of installed capacity. The government recently announced a ban on importation of bagged cement in an attempt to enhance greater market competition, encourage new investments, and stem the continuous rise in the price of cement. Such efforts have not yielded any benefits as the price of cement has increased unabated and the problem of supply insufficiency still exists. One of the main challenges plaguing the industry includes lack of sufficient funding to carry out operations, especially on a large scale. Most of the cement manufacturers do not have the financial capacity to operate at optimal levels and hence are unable to meet up to the high demand for cement. Only the quoted companies are able to raise funds from the public but such funds are often inadequate to meet the ever growing needs of their business.

Most industrialize economies have functional iron and steel producing industries where the slag output is utilized in the production of Ground Granulated Slag Cement (GGSC). The GGSC supplements the consumption of ordinary Portland cement. Thus the availability of GGSC enables the construction industry to meet the essential need of cement and shelter.

The use of GGSC in Nigeria will lower the prohibitive cost of cement significantly, since the production of GGSC involves lower energy consumption with substantial reduction in the complexity of the manufacturing processes and machineries.

9. Conclusion

The chemical characteristic and suitability of the Delta Steel slag from the production of steel in the Electric Arc Furnace were evaluated with the content development of GGSC in suitable blending proportion with ordinary Portland cement. The analysis indicates that the slag from DSC in comparison with the Nigeria Industrial Standard (NIS) is suitable for GGSC production with the limitation that the slag has a high iron content which can be normalized by the process of beneficiation using magnetic separators. With the institution of a granulating tank in the steel production chain of DSC, the process development for the production of GGSC in Nigeria would have been accomplished.

The utilization of DSC slag for cement production will eliminate the environmental impact challenges for the disposal of the slag; make cement and housing available at affordable cost. The Federal Government of Nigeria should as a matter of urgency facilitate the revitalization of Ajaokuta and Delta Steel Complex for the production of sufficient quantity of slag for the production of Ground Granulated Slag Cement.

10. Recommendations

(i) Granulating facilities should be provided at Delta Steel Complex (DSC)
(ii) Work should be carried out to construct a magnetic separator for the beneficiation of local slag.
(iii) Slag formers should be used to control and produce slag of desired composition from the furnace.

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